WHPI0 REVISIT DATA BOOK

Field Activity of JAMSTEC towards International Repeat Hydrography and Carbon Program
WHP P10 REVISIT DATA BOOK

Edited by
Takeshi Kawano (JAMSTEC),
Hiroshi Uchida (JAMSTEC)
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Preface

The observation line that we occupied during the period from 25th May to 2nd July, 2005 was mostly along the meridian of 149°20’E and was overlaid on WOCE Hydrographic Program: WHP P10 line with the northern extension to the coast of the Hokkaido, Japan. As the result, 30 new stations were added to the former P10 stations and the total number of WHP stations has increased to 124.

P10 is the third WHP line that IORGC/JAMSTEC occupied by following the CLIVAR/Carbon Repeat Hydrography Program (currently renamed as International Repeat Hydrography and Carbon Program: IRHC), which was advocated at OceanObs99.

The objectives of the program were defined as follows:

1) to investigate inter annual and longer-term variations in the ocean circulation and associated net property transports and their divergences,

2) to quantify net changes in water mass inventories and renewal rates on seasonal to decadal time series, and to explore their relationships to estimated ocean transport divergences and air-sea exchanges.

After OceanObs99, the Argo project has started and is getting the right track now. Argo has much more frequency of observation than any other hydrographic observation under IRHC. However, hydrographic observation still remains and will remain to be the only mean to directly measure the full suite of water characteristics with vertical high resolution and with high accuracy of measurements. Therefore, the IRHC and Argo Project are complementary to each other toward understanding of phenomena at shallower and intermediate depths. On the other hand, the unique long-term objectives of IRHC could be sharpened as “To investigate inter-annual and long-term variations in the ocean circulation and associated net property transports and their divergence, and to explore their relationships to air-sea exchange”. These unique objectives can be supported only through a global network of the core ship-based hydrography, which follows the traditional WOCE manner with full suite of its measurements.

The Ocean General Circulation Observational Research Program of IORGC/JAMSTEC** has a plan to carry out seven core ship-based hydrography along WHP P6, A10, I4+I3, P10, P3, P1 and P14 until 2007. Of these lines, re-visits of P6, A10, I4+I3, P10 and P3 were completed and quite a few excellent scientific results have already published by numerous number of scientists, not only of IORGC but also of other institutions throughout the world. Anyone can refer and use data from these re-visits without any restriction through data books we already published and through web sites of IORGC ***, CCHDO****, and CDIAC*****.

Lastly, we would heartily ask favors of all scientists to refer these data books as often as possible. Such references are the only proof that this repeat hydrography activity is closely connected to the science and makes all of us brave enough to continue to maintain the IRHC net work.


Masao Fukasawa

Deputy Director-General  IORGC/JAMSTEC,

Program Director  Ocean General Circulation Observational Research Program

IORGC/JAMSTEC

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*Institute of Observational Research for Global Change
**Japan Agency for Marine-Earth Science and Technology
****CLIVAR and Carbon Hydrographic Data Office (http://whpo.ucsd.edu/)
*****Carbon Dioxide Information Analysis Center (http://cdiac.ornl.gov/)
1 Cruise Narrative

1.1 Highlight

WOCE Line Designation: P10 (Extended to northern end of Japanese mainland up to Hokkaido)

Expedition Designation: MR05-02

Chief Scientist and Affiliation:

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Institute of Observational Research for Global Change (IORGC)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
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Tel: +81-46-867-9471, Fax: +81-46-867-9455
E-mail: kawanot@jamstec.go.jp

Ship: R/V MIRAI

Ports of Call: Sekinehama, Japan – Hachinohe, Japan – Guam, U.S.A.

Cruise Dates: May 25, 2005 – July 2, 2005

Number of Stations:

124 stations for CTD/Carousel Water Sampler

Geographic boundaries:

143° 44.01' E - 149° 23.31' E
4° 00.90’ S - 42° 15.20’ N

Floats and drifters deployed:

2 Argo Floats

Mooring deployed or recovered mooring:

NONE

1.2 Cruise Summary

(1) Geographic boundaries

MR05-02 occupied stations along about 149° 20’ E, from 42° 15’ N to 4° 00’ S.

(2) Station occupied

A total of 124 stations were occupied using a Sea-Bird Electronics 36 bottle carousel equipped with 12 liter Niskin X water sample bottles, a SBE911plus equipped with SBE35 deep ocean standards thermometer, SBE43 oxygen sensor, Seapoint sensors Inc. Chlorophyll Fluorometer and Benthos Inc. Altimeter and RDI Monitor ADCP.

Cruise track and station location are shown in Fig. 1.2.1. The stations south of 28°N were revisited of the previous P10 cruise conducted in 1994. The stations north of 34°N were designed to trace the track of Jason-1 altimeter.

(3) Sampling and measurements

Water samples were analyzed for salinity, oxygen, nutrients, CFC11, CFC12, CFC113, total alkalinity, DIC and pH. The sampling layers in dbar were 10, 50, 100, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3250, 3500, 3750, 4000, 4250, 4500, 4750, 5000, 5250, 5500, 5750 and bottom (minus 10 m). Samples for PON, 14C, 13C, 15N, Pu and 137Cs were also collected. The bottle depth diagram is shown in Fig. 1.2.2. Underway measurements of pCO2, temperature, salinity, oxygen, surface current, bathymetry and meteorological parameters were made along the cruise track. Biological parameters such as chlorophyll a and nitrogen fixation rate were measured at the selected stations.
(4) Floats and Drifters deployed

Two ARGO floats were launched along the cruise track. The launched positions of the ARGO floats are listed in Table 1.2.1.

Table 1.2.1. Launched positions of the ARGO floats.

<table>
<thead>
<tr>
<th>Float S/N</th>
<th>ARGOS ID</th>
<th>Date and Time of Reset (UTC)</th>
<th>Date and Time of Launch (UTC)</th>
<th>Location of Launch</th>
<th>CTD St. No.</th>
</tr>
</thead>
</table>

(5) Moorings deployed or recovered

No mooring was deployed or recovered during the cruise.
1.3 List of Principal Investigator and Person in Charge on the Ship

The principal investigator (PI) and the person in charge responsible for the major parameters measured on the cruise are listed in Table 1.3.1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Principal Investigator</th>
<th>Person in Charge on the Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underway</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADCP</td>
<td>Yasushi Yoshikawa (JAMSTEC)</td>
<td>Yasutaka Imai (GODI)</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>Takeshi Matsumoto (Univ. Ryukyus)</td>
<td>Yasutaka Imai (GODI)</td>
</tr>
<tr>
<td>Meteorology</td>
<td>Kunio Yoneyama (JAMSTEC)</td>
<td>Yasutaka Imai (GODI)</td>
</tr>
<tr>
<td>T-S</td>
<td>Takeshi Kawano (JAMSTEC)</td>
<td>Takayoshi Seike (MWJ)</td>
</tr>
<tr>
<td>pCO₂</td>
<td>Akihiko Murata (JAMSTEC)</td>
<td>Mikio Kitada (MWJ)</td>
</tr>
<tr>
<td><strong>Hydrography</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTD/O₂</td>
<td>Hiroshi Uchida (JAMSTEC)</td>
<td>Satoshi Ozawa (MWJ)</td>
</tr>
<tr>
<td>Salinity</td>
<td>Takeshi Kawano (JAMSTEC)</td>
<td>Fujio Kobayashi (MWJ)</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Ikuo Kaneko (JAMSTEC)</td>
<td>Takayoshi Seike (MWJ)</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Michio Aoyama (MRI)</td>
<td>Junko Hamanaka (MWJ)</td>
</tr>
<tr>
<td><strong>DIC</strong></td>
<td>Akihiko Murata (JAMSTEC)</td>
<td>Mikio Kitada (MWJ)</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>Akihiko Murata (JAMSTEC)</td>
<td>Fuyuki Shibata (MWJ)</td>
</tr>
<tr>
<td>pH</td>
<td>Akihiko Murata (JAMSTEC)</td>
<td>Taeko Ohama (MWJ)</td>
</tr>
<tr>
<td>CFCs</td>
<td>Kenichi Sasaki (JAMSTEC)</td>
<td>Katsunori Sagishima (MWJ)</td>
</tr>
<tr>
<td>LADCP</td>
<td>Shinya Kouketsu (JAMSTEC)</td>
<td>Shinya Kouketsu (JAMSTEC)</td>
</tr>
<tr>
<td>Δ¹⁴C &amp; δ¹³C</td>
<td>Yuichiro Kumamoto (JAMSTEC)</td>
<td>Akihiko Murata (JAMSTEC)</td>
</tr>
<tr>
<td>¹³Cs &amp; Pu</td>
<td>Michio Aoyama (MRI)</td>
<td>Akihiko Murata (JAMSTEC)</td>
</tr>
<tr>
<td>¹⁵N</td>
<td>Hisayuki Yoshikawa (Hokkaido Univ.)</td>
<td>Tomomi Takamura (Hokkaido Univ.)</td>
</tr>
<tr>
<td>Biology</td>
<td>Ken Furuya (Univ. Tokyo)</td>
<td>Satoshi Kitajima (Univ. Tokyo)</td>
</tr>
<tr>
<td><strong>Floats, Drifters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argo float</td>
<td>Nobuyuki Shikama (JAMSTEC)</td>
<td>Naoko Takahashi (MWJ)</td>
</tr>
</tbody>
</table>

GODE: Global Ocean Development Inc.
JAMSTEC: Japan Agency for Marine-Earth Science and Technology
MRI: Meteorological Research Institute, Japan Meteorological Agency
MWJ: Marine Works Japan, Ltd.
Univ. Ryukyus: University of the Ryukyus
1.4 Scientific Program and Methods

(1) Objectives of MR05-02 cruise project

It is well known that the oceans play a central role in determining global climate. However, heat and material transports in the ocean and their temporal changes have not yet been sufficiently quantified. Therefore, the global climate change is not understood satisfactorily. The purposes of this research are to evaluate heat and material transports including carbon, nutrients, etc., in the North Pacific and to detect its long term changes and basin-scale biogeochemical changes since the 1990s.

P10 is the hydrographic section nominally along 149°E from Hokkaido, Japan, to the coast of Papua New Guinea. The P10 cruise was the first in two WHP re-visit cruise aboard R/V MIRAI in 2005 followed by P3.

The other objectives of this cruise are as follows;
1) to observe surface meteorological and hydrological parameters as a basic data of the meteorology and the oceanography,
2) to observe sea bottom topography, gravity and magnetic fields along the cruise track to understand the dynamics of ocean plate and the accompanying geophysical activities,
3) to contribute to establishment of data base for model validation,
4) ARGO sensor calibration and its deployment in the western Pacific.

(2) Cruise overview

MR05-02 cruise was carried out during the period from May 25, 2005 to July 2, 2005. The cruise started from the coast of Hokkaido and sailed towards southeast along the track of Jason-1 (TOPEX/POSEIDON). This line was observed several times during the period from 1997–2000 as a part of the SAGE (Sub-Arctic Gyre Experiment) and called OICE (Oyashio Intensive observation line off Cape Erimo). The cruise course was changed southward at Station 105 (33°45′N, 149°20′E) and the stations from Station 73 (28°30′N, 149°20′E) were revisit of WOCE Hydrographic Program section P10. A total of 124 stations were observed. At each station, full-depth CTD profile and up to 36 water samples were taken and analyzed. Water samples were obtained from fixed layers with 12-liter Niskin bottles attached to 36-position SBE carousel water sampler. The sampling layers were 10, 50, 100, 150, 200, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3250, 3500, 3750, 4000, 4250, 4500, 4750, 5000, 5250, 5500, 5750 dbar and about 10 dbar above the bottom. Scientists of JAMSTEC and Meteorological Research Institute and technicians of Marine Works Japan Ltd. (MWJ) were responsible for analyzing water sample for salinity, dissolved oxygen, nutrients, CFCs, total carbon contents, alkalinity and pH. They also contributed to sampling for total organic carbon, radiocarbon and so on. Students of University of Tokyo and Hokkaido University joined the cruise for their research on chemical and biological oceanography. A scientist from University of the Ryukus was a principal investigator for geological parameters (topography, geo-magnetic field and gravity). Technicians from Global Ocean Development Inc. (GODI) had responsibility on a part of underway measurements such as current velocity by Acoustic Doppler Current Profiler (ADCP) geological parameters (topography, geo-magnetic field and gravity), and meteorological parameters. Two ARGO floats prepared by JAMSTEC were launched by MWJ technicians and ship crew.

(3) Cruise narrative

R/V Mirai departed Sekinehama (Japan) on May 25, 2005. She called on the port of Hachinohe (Japan) on May 26, 2005 for bunkering. She arrived at the first station on May 27 and made a cast for 445m. Before the first station, all watchstanders were drilled in the method of sample drawing. We made a cast at Station P10-1 on June 28, 2005 and then went to Guam, U.S.A. We observed 124 stations along approximately 149°20′E, which is, namely WHP P10. She arrived at Guam on July 2, 2005.

1.5 Major Problems and Goals not Achieved

Water sampler miss-fired 15 times, and consequently, samples were not obtained at 13 layers.
# 1.6 List of Participants

The members of the scientific party are listed in Table 1.6.1 along with their main tasks undertaken on the cruise.

<table>
<thead>
<tr>
<th>Name</th>
<th>Main tasks</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hideyuki FUTAMURA</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Junko HAMANAKA</td>
<td>Nutrients</td>
<td>MWJ</td>
</tr>
<tr>
<td>Miyo IKEDA</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Yasutaka IMAI</td>
<td>Meteorology</td>
<td>GODI</td>
</tr>
<tr>
<td>Tetsuya INABA</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Yoshiko ISHIKAWA</td>
<td>Carbon</td>
<td>MWJ</td>
</tr>
<tr>
<td>Kenichi KATAYAMA</td>
<td>Salinity</td>
<td>MWJ</td>
</tr>
<tr>
<td>Takeshi KAWAO</td>
<td>Chief Scientist / Salinity</td>
<td>IORGC/JAMSTEC</td>
</tr>
<tr>
<td>Mikio KITADA</td>
<td>Carbon</td>
<td>MWJ</td>
</tr>
<tr>
<td>Satoshi KITAJIMA</td>
<td>Biology</td>
<td>University of Tokyo</td>
</tr>
<tr>
<td>Fujio KOBAYASHI</td>
<td>Salinity</td>
<td>MWJ</td>
</tr>
<tr>
<td>Shinya KOUKETSU</td>
<td>LADCP/ADCP</td>
<td>IORGC/JAMSTEC</td>
</tr>
<tr>
<td>Asako KUBO</td>
<td>Nutrients</td>
<td>MWJ</td>
</tr>
<tr>
<td>Kazuma KUDO</td>
<td>Water Sampling</td>
<td>MWJ</td>
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<tr>
<td>Akihiko MURATA</td>
<td>Carbon</td>
<td>IORGC/JAMSTEC</td>
</tr>
<tr>
<td>Kimiko NISHIIJIMA</td>
<td>Dissolved Oxygen</td>
<td>MWJ</td>
</tr>
<tr>
<td>Tomohide NOGUCHI</td>
<td>CTD</td>
<td>MWJ</td>
</tr>
<tr>
<td>Taeko OHAMA</td>
<td>Carbon</td>
<td>MWJ</td>
</tr>
<tr>
<td>Shinya OKUMURA</td>
<td>Meteorology</td>
<td>GODI</td>
</tr>
<tr>
<td>Kentaro OYAMA</td>
<td>CTD</td>
<td>MWJ</td>
</tr>
<tr>
<td>Ryo OYAMA</td>
<td>Meteorology</td>
<td>GODI</td>
</tr>
<tr>
<td>Satoshi OZAWA</td>
<td>CTD</td>
<td>MWJ</td>
</tr>
<tr>
<td>Katsunori SAGISHIMA</td>
<td>CFCs</td>
<td>MWJ</td>
</tr>
<tr>
<td>Kenichi SASAKI</td>
<td>CFCs</td>
<td>JAMSTEC</td>
</tr>
<tr>
<td>Kenichiro SATO</td>
<td>Chief Technologist / Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Takayoshi SEIKE</td>
<td>Dissolved Oxygen</td>
<td>MWJ</td>
</tr>
<tr>
<td>Fuyuki SHIBATA</td>
<td>Carbon</td>
<td>MWJ</td>
</tr>
<tr>
<td>Naoko TAKAHASHI</td>
<td>CTD</td>
<td>MWJ</td>
</tr>
<tr>
<td>Tomomi TAKAMURA</td>
<td>C-13</td>
<td>Hokkaido University</td>
</tr>
<tr>
<td>Ayumi TAKEUCHI</td>
<td>Nutrients</td>
<td>MWJ</td>
</tr>
<tr>
<td>Tatsuya TANAKA</td>
<td>Salinity</td>
<td>MWJ</td>
</tr>
<tr>
<td>Tomokazu TANIGUCHI</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Hiroshi UCHIDA</td>
<td>LADCP/CTD</td>
<td>IORGC/JAMSTEC</td>
</tr>
<tr>
<td>Satoshi UDA</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Masahide WAKITA</td>
<td>CFCs</td>
<td>JAMSTEC</td>
</tr>
<tr>
<td>Hideki YAMAMOTO</td>
<td>CFCs</td>
<td>MWJ</td>
</tr>
<tr>
<td>Ai YASUDA</td>
<td>Dissolved Oxygen</td>
<td>MWJ</td>
</tr>
<tr>
<td>Masashi YASUNAGA</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
<tr>
<td>Atsushi YOSHIMURA</td>
<td>Water Sampling</td>
<td>MWJ</td>
</tr>
</tbody>
</table>

GODI: Global Ocean Development Inc.  
MWJ: Marine Works Japan Ltd.  
JAMSTEC: Japan Agency for Marine-Earth Science and Technology  
IORGC: Institute of Observational Research for Global Change  
MIO: Mutsu Institute for Oceanography
2 Underway Measurements

2.1 Navigation and Bathymetry

2 August 2005

(1) Personnel

Takeshi Matsumoto (University of the Ryukyus), PI for bathymetry
Yasutaka Imai (GODI)
Shinya Okumura (GODI)
Ryo Ohyama (GODI)

(2) Navigation

(2.1) Overview of the equipment

The ship’s position was measured by navigation system, made by Sena Co. Ltd, Japan. The system has two 12-channel GPS receivers (Leica MX9400N). GPS antennas were located at Navigation deck, offset to starboard and portside, respectively. We switched them to choose better receiving state when the number of GPS satellites decreased or HDOP increased. But the system sometimes lost the position while the receiving status became worse. The system also integrates gyro heading (Tokimec TG-6000), log speed (Furuno DS-30) and other navigation devices data on HP workstation. The workstation keeps accurate time using GPS Time server (Datum Tymserv2100) via NTP (Network Time Protocol). Navigation data was recorded as “SOJ” data every 60 seconds.

(2.2) Data period

07:00, 25 May 2005 to 00:00, 2 July 2005 (UTC)

(3) Bathymetry

(3.1) Overview of the equipment

R/V MIRAI equipped a Multi Narrow Beam Echo Sounding system (MNBES), SEABEAM 2112.004 (SeaBeam Instruments Inc.). The main objective of MNBES survey is collecting continuous bathymetry data along ship’s track to make a contribution to geological and geophysical investigations and global datasets. Data interval along ship’s track was max. 17 seconds at 6,000 m. To get accurate sound velocity of water column for ray-path correction of acoustic multibeam, we used Surface Sound Velocimeter (SSV) data at the surface (6.2 m), and sound velocity profiles calculated from temperature and salinity data obtained from the nearest CTD cast by using the equation of Mackenzie (1981).

(3.2) System configuration and performance

<table>
<thead>
<tr>
<th>System</th>
<th>SEABEAM 2112.004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>12 kHz</td>
</tr>
<tr>
<td>Transmit beam width</td>
<td>2 degree</td>
</tr>
<tr>
<td>Transmit power</td>
<td>20 kW</td>
</tr>
<tr>
<td>Transmit pulse length</td>
<td>3 to 20 msec.</td>
</tr>
<tr>
<td>Depth range</td>
<td>100 to 11,000 m</td>
</tr>
<tr>
<td>Beam spacing</td>
<td>1 degree athwart ship</td>
</tr>
<tr>
<td>Swath width</td>
<td>150 degree (max)</td>
</tr>
<tr>
<td>Depth accuracy</td>
<td>Within &lt; 0.5 % of depth or ±1m, whichever is greater, over the entire swath.</td>
</tr>
<tr>
<td></td>
<td>(Nadir beam has greater accuracy; typically within &lt; 0.2 % of depth or ±1m, whichever is greater)</td>
</tr>
</tbody>
</table>
(3.3) Data period

Bathymetric survey was carried out on the CTD observation line during the cruise.
26 May 2005 (P10N_143) to 28 June 2005 (P10_1)

(3.4) Data processing

(3.4.1) Editing for the navigation data

Erroneous data in the navigation data are manually removed (by using “mbedit” module of the mbsystem) and linearly interpolated.

(3.4.2) Sound velocity correction

The continuous bathymetry data are split into small areas around each CTD station. For each small area, the bathymetry data are corrected using a sound velocity profile calculated from the CTD data in the area. The equation of Mackenzie (1981) is used for calculating sound velocity. The data processing is carried out using “mbbath” module of the mbsystem.

(3.4.3) Gridding

Gridding for the bathymetry data are carried out using the HIPS software version 5.4 (CARIS, Canada). Firstly, low-quality data during the CTD cast and the ship’s drift are removed. Secondly, spikes in the data are removed by “Surface Cleaning” function of the software with following parameters.

Tiling: by size (Minimum size of tile: 163.84 [m])
Degree of polynomial: 1 (tiled plane)

Cleaning

Shallow threshold: 1.000, sigma = 68.26 [%]
Deep threshold: 1.000, sigma = 68.26 [%]
Minimum residual required for rejection: 10.000 [m]

Thirdly, remaining erroneous data are manually removed and normal data, which have been removed by the “Surface Cleaning” function, are manually recovered by “Swath Editor” and “Subset Editor” functions of the software. Finally, the bathymetry data are gridded by “Interpolate” function of the software with following parameters.

Matrix size: 5 × 5
Number of nearneighbors: 18

Reference

2.2 Surface Meteorological Observation
27 September 2006

(1) Personnel
Kunio Yoneyama (JAMSTEC)
Yasutaka Imai (GODI)
Shinya Okumura (GODI)
Ryo Ohyama (GODI)
Norio Nagahama (GODI)

(2) Objective
As a basic dataset that describes weather conditions during the cruise, surface meteorological observation was continuously conducted.

(3) Methods
There are two different surface meteorological observation systems on 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 2.2.1. All SMET data were collected and processed 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 (the location possibly affect on the accuracy of the capture rate of the gauge), 2) SOAR’s anemometer has better starting threshold wind speed (1 m/sec) comparing to SMET’s anemometer (2 m/sec), and 3) SMET’s radiometers record data with 10 W/m² unit, while SOAR takes 1 W/m² unit.

SOAR system was designed and constructed by the Brookhaven National Laboratory (BNL), USA, for an accurate measurement of solar radiation on the ship. Details of SOAR can be found at http://www.gim.bnl.gov/soar/.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Parameter</th>
<th>Manufacturer / type</th>
<th>Location / height from sea level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermometer*1</td>
<td>air temperature</td>
<td>Vaisala, Finland / HMP45A</td>
<td>compass deck*2 / 21 m</td>
</tr>
<tr>
<td></td>
<td>relative humidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermometer</td>
<td>sea temperature</td>
<td>Koshin Denki, Japan / RFN1-0</td>
<td>4th deck / –5 m</td>
</tr>
<tr>
<td>Barometer</td>
<td>pressure</td>
<td>Yokogawa, Japan / F-451</td>
<td>captain deck / 13 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*1 Gill aspirated radiation shield 43408 made by R. M. Young, USA is attached.
*2 There are two thermometers at starboard and port sides.

Table 2.2.1. Instruments and locations of SMET.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Parameter</th>
<th>Manufacturer / type</th>
<th>Location / height from sea level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemometer</td>
<td>wind speed/direction</td>
<td>R. M. Young, USA / 05106</td>
<td>foremast / 25 m</td>
</tr>
<tr>
<td>Rain gauge</td>
<td>rainfall accumulation</td>
<td>R. M. Young, USA / 50202</td>
<td>foremast / 24 m</td>
</tr>
<tr>
<td>Radiometer</td>
<td>short wave radiation</td>
<td>Eppley, USA / PSP</td>
<td>foremast / 25 m</td>
</tr>
<tr>
<td></td>
<td>long wave radiation</td>
<td>Eppley, USA / PIR</td>
<td>foremast / 25 m</td>
</tr>
</tbody>
</table>

Table 2.2.2. Instruments and locations of SOAR.
(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 beginning of the average). They are simple mean of 8 samples (10 samples minus maximum/minimum values) to exclude singular values. Liner 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 on the deck, we used air temperature/relative humidity data taken at upwind side. Dew point temperature was produced 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 contains 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), downwelling shortwave radiation (W/m²), and downwelling longwave radiation (W/m²).

Missing values are expressed as “9999”.

(5) Data Quality

To ensure the data quality, each sensor was calibrated as follows. Since there is a possibility for fine time resolution data sets to have some noises caused (generated) by turbulence, it is recommended to filter them out (ex. hourly mean) from this 1-minute mean data sets depending on the scientific purpose.

T/RH sensor:

Temperature and humidity probes were calibrated before/after the cruise by the manufacturer. Certificated accuracy of 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 and after the cruise. The results are as follows.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Mean difference between T (SMET) and T (portable) is</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>–0.3 ± 0.1 (°C) at port side, –0.2 ± 0.4 (°C) at starboard side.</td>
</tr>
</tbody>
</table>

Relative Humidity (%)

Mean difference between RH (SMET) and RH (portable) is

0 ± 1 (%) at port side, 0 ± 0 (%) at starboard side.

Pressure sensor:

Using calibrated portable barometer (Vaisala, Finland / PTB220, certificated accuracy is better than ± 0.1 hPa), pressure sensor was checked before/after the cruise. Mean difference of SMET pressure sensor and portable sensor is 0.0 ± 0.1 hPa.

Anemometer:

Using digital tester (Hioki, Japan / 3805), post calibration was conducted by the GODI.

Post-calibration date: Sep. 7, 2005

<table>
<thead>
<tr>
<th>Wind direction check:</th>
<th>better than ± 2 °</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set value</td>
<td>6 36 64 96 126 156 185 215 244 275 306 336</td>
</tr>
<tr>
<td>Measured value</td>
<td>6 30 68 97 127 156 186 216 245 275 306 337</td>
</tr>
<tr>
<td>Difference</td>
<td>0 0 –4 –1 –1 0 –1 –1 –1 0 0 –1</td>
</tr>
</tbody>
</table>

Precipitation:

Before the cruise, we put water into the rain gauge to check their linearity between the indicated values and water amount input. Expected accuracy is better than ± 1 mm corresponding to the sensor’s specification. The results are as follows, and data were corrected using this relationship.
<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>Mean</th>
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</thead>
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<tr>
<td>minimum input water volume (cc)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>minimum measured value (mm)</td>
<td>0.7</td>
<td>0.7</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>maximum input water volume (cc)</td>
<td>516.0</td>
<td>514.5</td>
<td>513.0</td>
<td>514.5</td>
</tr>
<tr>
<td>maximum measured value (mm)</td>
<td>51.2</td>
<td>51.1</td>
<td>51.2</td>
<td>51.2</td>
</tr>
</tbody>
</table>

Radiation sensors:

Short wave and long wave radiometers were calibrated by the manufacturer, Remote Measurement and Research Company, USA, prior to the cruise.

(6) Data periods

1200 UTC, May 26, 2006-2300 UTC, July 1, 2006

Only SST data is available from 1230 UTC, May 26, 2006.

(7) Point of contact

Kunio Yoneyama (yoneyamak@jamstec.go.jp)
JAMSTEC / IORGC, 2-15, Natsushima, Yokosuka 237-0061, Japan

Figure 2.2.1. 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. Day 146 corresponds to May 26, 2006.
2.3 Thermosalinograph and related measurements

22 January 2004

(1) Personnel

Takayoshi Seike (MWJ)
Takeshi Kawano (JAMSTEC)

(2) Objective

To measure salinity, temperature, dissolved oxygen, and fluorescence of near-sea surface water.

(3) Methods

Continuous Sea Surface Water Monitoring System (Nippon Kaiyo Co., Ltd.) has six kinds of sensors and can automatically and continuously measure salinity, temperature, dissolved oxygen, fluorescence and particle size of plankton in near-sea surface water every 1-minute. This system is located in “sea surface monitoring laboratory” on R/V Mirai and connected to shipboard LAN-system. Measured data is stored in a hard disk of PC every 1-minute together with time and position of the ship, and displayed in the data management PC machine.

Near-surface water was continuously pumped up to the laboratory and flowed into the Continuous Sea Surface Water Monitoring System through a vinyl-chloride pipe. The flow rate for the system is controlled by several valves and is set at 12 l/min except with fluorometer (about 0.3 l/min). The flow rate is measured with two flow meters and each value is checked every day.

Specification of the each sensor in this system is listed below.

a) Temperature and Salinity sensors

SEACAT THERMOSALINOGRAPH
Model: SBE-21, Sea-Bird Electronics, Inc.
Serial number: 2126391-2641

b) Bottom of ship thermometer

Model: SBE 3S, Sea-Bird Electronics, Inc.
Serial number: 032175
Measurement range: Temperature -5 to +35 °C
Resolution: ± 0.001 °C
Stability: 0.002 °C year\(^{-1}\)

(c) Dissolved oxygen sensor

Model: 2127A, Oubisufair Laboratories Japan Inc.
Serial number: 44733
Measurement range: 0 to 14 ppm
Accuracy: ± 1 % at 5 °C of correction range
Stability: 1 % month\(^{-1}\)

(d) Fluorometer

Model: 10-AU-005, Turner Designs
Serial number: 5562 FRXX
Detection limit: 5 ppt or less for chlorophyll-a
Stability: 0.5 % month\(^{-1}\) of full scale
e) Particle Size sensor

- Model: P-05, Nippon Kaiyo Co., Ltd.
- Serial number: P5024
- Measurement range: 0.02681 mm to 6.666 mm
- Accuracy: ± 10% of range
- Reproducibility: ± 5%
- Stability: 5% week⁻¹

f) Flow meter

- Model: EMARG2W, Aichi Watch Electronics Ltd.
- Serial number: 8672
- Measurement range: 0 to 30 l min⁻¹
- Accuracy: ± 1%
- Stability: ± 1% day⁻¹

The monitoring periods (UTC) are listed below.

26-Mar-05 13:31 to 30-Jun-05 02:45

(4) Comparison of salinity data with sampled salinity

We sampled seawater for salinity measurement about twice a day for salinity sensor calibration. All salinity samples were collected from the course of the system while on station or from regions with weak horizontal gradients. All samples were analyzed on Guildline 8400B. The results were shown in Table 2.3.1.

<table>
<thead>
<tr>
<th>Date [UTC]</th>
<th>Time [UTC]</th>
<th>Salinity data</th>
<th>Bottle Salinity [PS-S-78]</th>
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</tbody>
</table>
2.4 Underway pCO₂

31 August, 2006

(1) Personnel
Akihiko Murata (IORGC, JAMSTEC)
Fuyuki Shibata (MWJ)
Mikio Kitada (MWJ)
Taeko Ohama (MWJ)
Yoshiko Ishikawa (MWJ)

(2) Introduction
Concentrations of CO₂ in the atmosphere are now increasing at a rate of 1.5 ppmv y⁻¹ due to human activities such as burning of fossil fuels, deforestation, cement production, and so on. It is an urgent task to estimate as accurately as possible the absorption capacity of the ocean against the increased atmospheric CO₂, as well as to clarify the mechanism of CO₂ absorption, because the magnitude of predicted global warming depends on the levels of CO₂ in the atmosphere, and 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 aimed to quantify how much anthropogenic CO₂ is absorbed in the surface ocean of the North 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 CO₂ measuring system (Nippon ANS, Ltd) installed in the R/V Mirai of JAMSTEC. The system comprises of a non-dispersive infrared gas analyzer (NDIR, BINOS® model 4.1, Fisher-Rosemount), an air-circulation module and a showerhead-type equilibrator. To measure concentrations (mole fraction) of CO₂ in dry air (xCO₂a), 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 xCO₂a. The flow rate of the equilibrated air was 500 – 800 ml min⁻¹. The seawater was taken by a pump from an intake placed at approx. 4.5 m below the sea surface. The flow rate of seawater in the equilibrator was 500 – 800 ml min⁻¹.

The CO₂ measuring system was set to repeat the measurement cycle such as 4 kinds of CO₂ standard gases (Table 2.4.1), xCO₂a (twice), xCO₂s (7 times). This measuring system was run automatically throughout the cruise by a PC control.

(4) Quality control
Concentrations of CO₂ of the standard gases are listed in Table 2.4.1, which were calibrated by JAMSTEC primary standard gases. The CO₂ concentrations of the primary standard gases were calibrated by C.D. Keeling of the Scripps Institution of Oceanography, La Jolla, CA, USA.

Since differences of concentrations of the standard gases between before and after the cruise were allowable (< 0.1 ppmv), the averaged concentrations (Table 2.4.1) were adopted for subsequent calculations.

In actual shipboard observations, signals of NDIR usually reveal a trend. The trend was adjusted linearly using 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 xCO₂s were adjusted based on Gordon and Jones (1973), although the temperature increases were slight, being ~ 0.3 °C.

We checked values of xCO₂a and xCO₂s by examining signals of NDIR on recorder charts, and by plotting the xCO₂a and xCO₂s as a function of sequential day, longitude, sea surface temperature and sea surface salinity.
Table 2.4.1. Concentrations of CO$_2$ standard gases used in the P10 revisit cruise.

<table>
<thead>
<tr>
<th>Cylinder no.</th>
<th>Concentrations (ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CQB17639</td>
<td>262.94</td>
</tr>
<tr>
<td>CQB09291</td>
<td>320.42</td>
</tr>
<tr>
<td>CQB09292</td>
<td>381.04</td>
</tr>
<tr>
<td>CQB09293</td>
<td>420.76</td>
</tr>
</tbody>
</table>

Reference

2.5 Acoustic Doppler Current Profiler

23 August 2006

(1) Personnel

Yasushi Yoshikawa (JAMSTEC)
Shinya Kouketsu (JAMSTEC)
Yasutaka Imai (GODI)
Shinya Okumura (GODI)
Ryo Ohyama (GODI)

(2) Instrument and method

The instrument used was an RDI 76.8 kHz unit, hull-mounted on the centerline and approximately 23 m aft of the bow at the water line. The firmware version was 5.59 and the data acquisition software was RDI VMDAS Version 1.4. Operation was made from the first CTD station to the last CTD station. The instrument was used in water-tracking mode during the most of operations, recording each ping raw data in 8 m × 90 bin from about 23 m to 735 m in depth. Typical sampling interval was 3.5 seconds. Bottom track mode was added in the northernmost shallow water region. GPS gave navigation data. Two kinds of compass data were recorded. One compass was the ship’s gyrocompass, which is connected the ADCP system directory, and its data were stored with the ADCP data. Current field based on the gyrocompass was used to check the operation and the performance on board. Another compass used was Inertial Navigation Unit (INU), DRU-H, Honeywell Inc. Its accuracy is 1.0 mile (about 0.056 degree) and had already set on zero bias before the beginning of the cruise. The INU compass data were stored independently, and combined with the ADCP data after the cruise.

(3) Performance and quick view of the ADCP data on board

The performance of the ADCP instrument was almost good throughout the cruise: on streaming, profiles usually reached about 600 m (652384 pings of all 953103 pings till June, 27). Profiles were sometimes rather bad on CTD station. The profiles did not reach so far, from 200 m to 500 m and the ADCP signal was typically weak at about 350 m in depth. It is probably due to babbles from the bow-thruster. Echo intensity was relatively weak in the sea south of 35 °N in the subtropical and tropical North Pacific. It is probably due to weak reflection of the echo. The performance of the ADCP was relatively bad on streaming in these regions.

We processed the ADCP data in this cruise on board as described below. ADCP-coordinate velocities were converted to the earth-coordinate velocities using the ship’s heading, roll and pitch data form the INU. The earth-coordinate currents were obtained by subtracting ship velocities from the earth-coordinate velocities. The ship velocities were obtained from the moving distances for 5 minutes, which were measured by GPS data. The noise of the GPS position data was filtered out by 15-sec running mean. The errors of the estimated ship velocities are within 10 cm/s. The currents obtained in this cruise were shown in the preliminary report on the ship (figures are not shown here).

After this cruise the parameters of the misalignment and the scale factor would be evaluated by using the bottom track data obtained both in this cruise and in the engineering test cruise made just before this cruise.

(4) Data Processing

Corrections of the misalignment and the scale factor were made after the cruise using the bottom track data. The bottom track data used was obtained during the engineering test cruise carried out just before the P10_revisit cruise. The misalignment angle calculated was 0.05 degree and the scale factor was 0.975. These parameters were similar to those calculated in August 2003. Criteria for the correlation less than 64 and error velocity more than 20 mm/s are removed here. Therefore the error is estimated at 20 mm/s.

Raw data are filtered using the median filter on every 3 minutes. There are about 90 data in one ensemble. In vertical direction, 3 bins data are used, which would mean 24 m averaging in the filtering process. Time series of upper 25 bins average flow are calculated using the 3 minutes sub set. The continuity of the series is examined in order to use each to average on the CTD sites and on streaming between the sites. Typically, the time series of the flow are stable on the CTD sites, where the standard deviation is 38 mm/s. The variability is likely to correspond to the temporal tidal motion. The data of almost all time stamps are used for averaging. On the other hand, the time
series of that on streaming between the CTD sites are somewhat irregular, where the standard deviation is 63 mm/s. It is likely to be due to the variability in space with temporal tidal motion. The mismatch between the ship velocity obtained from the GPS and water column velocity of ADCP was found when the ship was accelerated and/or decelerated. Available time stamp was found using the continuity of the time series when the ship speed was almost constant. In the averaging process, we use the 40 % criterion of the maximum frequency. In the next step, we averaged the subset at each CTD station and at streaming between the stations. Each mean profile is calculated with depth correction using the CTD data. Vertical grids are put on every 20 m. Available frequency for averaging was set as 40 % of the most counts. It concludes almost good continuity of the vertical profile.

Following is the features of the analyzed dataset. The mean available depth range is 642 m on the CTD stations and 576 m on streaming, respectively. There are non-available layer in the subsurface around 350 m between 10 °N and 23 °N. It appears more on streaming case, and sometimes the subsurface hole connects to the deeper non-available depth. The reason of the appearing hole should be the weak signal of reflection, which is associated with the meridional structure or distribution of the reflector. The available depth range is full in the subtropical region between 25 °N and 35 °N. Standard deviation of the flow is 4.0 cm/s and 6.4 cm/s. They are almost same of those of sub-set. Vertical profile of the standard deviation is similar to each other, except of the bias. It is shown in Fig B. The value is relative bigger where the strong flow exists, especially around 29 °N, 23 °N, 19 °N and 8 °N.

(5) Current distributions observed

Current fields at 100 m is shown in Fig 6 (p.97). The major currents were clearly observed by the ADCP; the Oyashio, the Kuroshio Extension and the equatorial currents. The Oyashio appeared near the southern coast off the Hokkaido. The southern westward current was barotropic and it penetrated the deepest layer measured. The Kuroshio Extension existed around 36 °N across the ship track. The maximum speed near the sea surface was 1.8 m/s at 36° 22’ N. The southern shift of the maximum speed with depth was observed; the maximum speed at 600 m depth was 0.5 m/s at 35° 52’ N. The eddy-like flow pattern appeared in the mixed water region between the Oyashio and the Kuroshio Extension. The westward flow was dominant in the south of the Kuroshio Extension. The flow was almost barotropic in the subtropical region. However, the flow showed baroclinic feature in the region between 5 °N and 20 °N. The North Equatorial Current was seen around 10 °N. The Equatorial Counter Current was seen between 1 °N and 6 °N. The eastward flow of the Equatorial Under Current distributed just north of the equator, whose core appeared at 240 m at 1° 53’ N with a zonal speed of 0.79 cm/s. On the other hand, the core of the meridional component existed around the equator clearly. It might be an eddy or a meander feature of the current. The South Equatorial Current was seen from the equator to the southern hemisphere. The strong current along the coast was observed near the coast of the Papua New Guinea.

(6) Data Structure

The record structure of the data set A, where file name is ‘ADCP_A’, is described below. The file consists of 259 profiles, 130 of the CTD sites and 129 of the streaming. Each profile consists of header and data. The header has three lines representing analyzed site, date and time, and position. The data has 35 layers in which depth, zonal velocity, meridional velocity, and standard error of each grid are stored. Unit of depth is in meter. Unit of flow is in m/s. On the CTD station, the CTD station name (e.g. ‘143_1’) is recorded as the analyzed site in the header. Mean time and position were calculated and recorded using the ADCP profiles during the CTD operation was made. On the way to next CTD station, hyphenated two CTD station names (e.g. ‘143_1-142_1’) are recorded as the analyzed site in the header. Recorded time and position are mean for the available ADCP profiles. The ‘99.999’ in the data represents no available data stored.
### [data structure of the data set A]

**Line 1: header 1**
- Column 01-10: cruise code
- Column 12-15: WHP line name
- Column 17-27: analyzed site

**Line 2: header 2**
- Column 01-10: date (mm/dd/yyyy)
- Column 12-16: time (hh:mm)

**Line 3: header 3**
- Column 01-09: latitude (deg,min,N/S)
- Column 11-20: longitude (deg,min,E/W)

**Line 4-38: flow data in each depth level**
- Column 01-05: depth (m)
- Column 07-12: zonal velocity (m/s)
- Column 14-19: meridional velocity (m/s)
- Column 21-26: standard error (m/s)

---

Flow data processed in every three minutes are stored in the data set B, where the file name is ‘ADCP_B’. The data structure is the same as that of the data set B, except for the analyzed site in the header 1. Sequential number is written in the record as ‘$$$$$$’. 

### [data structure of the data set B: every 3 minutes]

**Line 1: header 1**
- Column 01-10: cruise code
- Column 12-15: WHP line name
- Column 17-27: analyzed site

**Line 2: header 2**
- Column 01-10: date (mm/dd/yyyy)
- Column 12-16: time (hh:mm)

**Line 3: header 3**
- Column 01-09: latitude (deg,min,N/S)
- Column 11-20: longitude (deg,min,E/W)

**Line 4-38: flow data in each depth level**
- Column 01-05: depth (m)
- Column 07-12: zonal velocity (m/s)
- Column 14-19: meridional velocity (m/s)
- Column 21-26: standard error (m/s)


3 Hydrographic Measurement Techniques and Calibrations

3.1 CTD/O₂ Measurements

25 October 2005

(1) Personnel

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(2) Winch arrangements

The CTD package was deployed by using 4.5 Ton Traction Winch System (Dynacon, Inc., USA), which was installed on the R/V Mirai in April 2001. The CTD Traction Winch System with the Heave Compensation Systems (Dynacon, Inc., USA) is designed to reduce cable stress resulting from load variation caused by wave or vessel motion. The system is operated passively by providing a noding boom crane that moves up or down in response to line tension variations. Primary system components include a complete CTD Traction Winch System with up to 10 km of 9.53 mm armored cable (Ocean Cable and Communication Co.), a cable rocker and Electro-Hydraulic Power Unit, a noding-boom crane assembly, two hydraulic cylinders and two hydraulic oil/nitrogen accumulators mounted within a single frame assembly. The system also contains related electronic hardware interface and a heave compensation computer control program.

(3) Overview of the equipment

The CTD system, SBE 911plus system (Sea-Bird Electronics, Inc., USA), is a real time data system with the CTD data transmitted from a SBE 9plus underwater unit via a conducting cable to the SBE 11plus deck unit. The SBE 11plus deck unit is a rack-mountable interface which supplies DC power to underwater unit, decodes serial data stream, formats data under microprocessor control, and passes the data to a companion computer. The serial data from the underwater unit is sent to the deck unit in RS-232 NRZ format using a 34,560 Hz carrier-modulated differential-phase-shift-keying (DPSK) telemetry link. The deck unit decodes the serial data and sends them to a personal computer to display, at the same time, to storage in a disk file using SBE SEASOFT software.

The SBE 911plus system acquires data from primary, secondary and auxiliary sensors in the form of binary numbers corresponding to the frequency or the voltage outputs from those sensors at 24 samples per second. The calculations required to convert raw data to engineering units of the parameters are performed by the SBE SEASOFT in real-time. The same calculations can be carried out after the observation using data stored in a disk file.

The SBE 911plus system controls 36-position SBE 32 Carousel Water Sampler. The Carousel accepts 12-litre water sample bottles. Bottles are fired through the RS-232C modem connector on the back of the SBE 11plus deck unit while acquiring real time data. The 12-litre Niskin-X water sample bottle (General Oceanics, Inc., USA) is equipped externally with two stainless steel springs. The external springs are ideal for applications such as trace metal analysis because the inside of the sampler is free from contaminants from springs.

SBE’s temperature (SBE 3) and conductivity (SBE 4) sensor modules were used with the SBE 9plus underwater unit fixed by a single clamp and "L" bracket to the lower end cap. The conductivity cell entrance is co-planar with the tip of the temperature sensor’s protective steel sheath. 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 compact, modular unit consisting of a centrifugal pump head and a brushless DC ball bearing motor contained in an aluminum underwater housing pump (SBE 5T) flushes water through sensor tubing at a constant rate independent of the CTD’s motion. Motor speed and pumping rate (3,000 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. SBE’s dissolved oxygen sensor (SBE 43) was placed between the conductivity sensor module and the pump. Auxiliary sensors, Deep Ocean Standards Thermometer (SBE 35), altimeter and fluorometer, were also used with the SBE 9plus underwater unit. The SBE 35
position in regard to the SBE 3 is shown in Figure 3.1.1.

It is known that the CTD temperature data is influenced by motion (pitching and rolling) of the CTD package. In order to reduce the motion of the CTD package, a heavy stainless frame (total weight of the CTD package without sea water in the bottles is about 1,000 kg) was used and an aluminum plate ($54 \times 90$ cm) was attached to the frame (Figure 3.1.1).

**Summary of the system used in this cruise**

**Deck unit:**
- SBE, Inc., SBE 11plus, S/N 0308

**Under water unit:**
- SBE, Inc., SBE 9plus, S/N 79511 (Pressure sensor: S/N 0677)

**Temperature sensor:**
- SBE, Inc., SBE 3, S/N 1464 (primary)
- SBE, Inc., SBE 3, S/N 1525 (secondary)

**Conductivity sensor:**
- SBE, Inc., SBE 4, S/N 1203 (primary)
- SBE, Inc., SBE 4, S/N 3036 (secondary, from P10N_143 to P10_53)
- SBE, Inc., SBE 4, S/N 1088 (secondary, from P10_52 to P10_27)
- SBE, Inc., SBE 4, S/N 2854 (secondary, from P10_26 to P10_1)

**Oxygen sensor:**
- SBE, Inc., SBE 43, S/N 0391 (primary, from P10N_143 to P10N_122)
- SBE, Inc., SBE 43, S/N 0767 (primary, from P10N_121 to P10_68, and P10_28 to 1)
- SBE, Inc., SBE 43, S/N 0390 (secondary)

**Pump:**
- SBE, Inc., SBE 5T, S/N 3118 (primary)
- SBE, Inc., SBE 5T, S/N 3293 (secondary)

**Altimeter:**
- Benthos Inc., PSA-916T, S/N 1157

**Deep Ocean Standards Thermometer:**
- SBE, Inc., SBE 35, S/N 0045

**Fluorometer:**
- Seapoint sensors, Inc., S/N 2579
  (without fluorometer from P10N_134 to 132, P10N_112 to P10_68, and P10_28 to 1)

**Carousel Water Sampler:**
- SBE, Inc., SBE 32, S/N 0278

**Water sample bottle:**
- General Oceanics, Inc., 12-litre Niskin-X (no TEFNOL coating)

Figure 3.1.1. The CTD package (left) and the SBE 35 position in regard to the SBE 3 temperature sensors (right).
(4) Pre-cruise calibration

(4.1) Pressure

The Paroscientific series 4000 Digiquartz high pressure transducer (Paroscientific, Inc., 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 15,000 psia (0 to 10,332 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 (MODEL 415K-187) 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).

Pre-cruise sensor calibrations were performed at SBE, Inc., USA. The following coefficients were used in the SEASOFT:

\[ S/N \text{ 0677, 2 July 2002} \]

\[ c_1 = -62072.94 \]
\[ c_2 = -1.176956 \]
\[ c_3 = 1.954420 \times 10^{-2} \]
\[ d_1 = 0.027386 \]
\[ d_2 = 0.0 \]
\[ t_1 = 30.05031 \]
\[ t_2 = -4.744833 \times 10^{-4} \]
\[ t_3 = 3.757590 \times 10^{-6} \]
\[ t_4 = 3.810700 \times 10^{-9} \]
\[ t_5 = 0.0 \]

Pressure coefficients are first formulated into

\[ c = c_1 + c_2 \times U + c_3 \times U^2 \]
\[ d = d_1 + d_2 \times U \]
\[ t_0 = t_1 + t_2 \times U + t_3 \times U^2 + t_4 \times U^3 + t_5 \times U^4 \]

where \( U \) is temperature in degrees Celsius. The pressure temperature, \( U \), is determined according to

\[ U (\text{°C}) = M \times (12 \text{ bit pressure temperature compensation word}) – B \]

The following coefficients were used in SEASOFT:

\[ S/N \text{ 0677} \]
\[ M = 0.0128041 \]
\[ B = -9.324136 \]

(in the underwater unit system configuration sheet dated on 22 February 2002)

Finally, pressure is computed as

\[ P (\text{psi}) = c \times [1 - (t_0^2/t_2)] \times [1 - d \times [1 - (t_0^2/t_2)]] \]

where \( t \) is pressure period (msec). 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 above automatically.

Pressure sensor calibrations against a dead-weight piston gauge (Bundenberg Gauge Co. Ltd., UK; Model 480DA, S/N 23906) are performed at JAMSTEC (Yokosuka, Kanagawa, JAPAN) by Marine Works Japan Ltd. (MWJ), usually once in a year in order to monitor sensor time drift and linearity. The pressure sensor drift is known to be primarily an offset drift at all pressures rather than a change of span slope. The pressure sensor hysteresis is typically 0.2 dbar. The following coefficients for the sensor drift correction were also used in SEASOFT:

\[ S/N \text{ 0677, 13 April 2003} \]
\[ \text{slope} = 0.99998953 \]
\[ \text{offset} = -0.44425 \]

The drift-corrected pressure is computed as

\[ \text{Drift-corrected pressure (dbar)} = \text{slope} \times (\text{computed pressure in dbar}) + \text{offset} \]

Result of the pressure sensor calibration against the dead weight piston gauge is shown in Figure 3.1.2. Time drift of the pressure sensor based on the offset and the slope of the calibrations is also shown in Figure 3.1.3.
(4.2) 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 10,500 (6,800) meters by titanium (aluminium) housing. The sensor output frequency ranges from approximately 5 to 13 kHz corresponding to temperature from –5 to 35 °C. The output frequency is inversely proportional to the square root of the thermistor resistance, which controls the output of a patented Wien Bridge circuit. The thermistor resistance is exponentially related to temperature. The SBE 3 thermometer has a nominal accuracy of 0.001 °C, typical stability of 0.0002 °C/month and resolution of 0.0002 °C 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). A sensor is designated as an SBE 3plus only after demonstrating drift of less than 0.001 °C during a six-month screening period. In addition, the time response is carefully measured and verified to be 0.065 ± 0.010 seconds.

Pre-cruise sensor calibrations were performed at SBE, Inc., USA. The following coefficients were used in SEASOFT:

**S/N 1464 (primary), 19 April 2005**

\[ g = 4.84385804 \times 10^{-3} \]
\[ h = 6.80766786 \times 10^{-4} \]
\[ i = 2.69831319 \times 10^{-5} \]
\[ j = 2.13061451 \times 10^{-6} \]
\[ f_0 = 1000.000 \]

**S/N 1525 (secondary), 19 April 2005**

\[ g = 4.84608198 \times 10^{-3} \]
\[ h = 6.75358139 \times 10^{-4} \]
\[ i = 2.65523364 \times 10^{-5} \]
\[ j = 2.13525896 \times 10^{-6} \]
\[ f_0 = 1000.000 \]
Temperature (ITS-90) is computed according to

$$\text{Temperature (ITS-90)} = \frac{1}{g + h \cdot \ln(f_0/f) + i \cdot \ln^2(f_0/f) + j \cdot \ln^3(f_0/f)} - 273.15$$

where $f$ is the instrument frequency (kHz).

Time drift of the SBE 3 temperature sensors based on the laboratory calibrations is shown in Figure 3.1.4.

(4.3) 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 10,500 meters. The impedance between the center and the end electrodes is determined by the cell geometry and the specific conductance of the fluid within the cell. The conductivity cell composes a Wien Bridge circuit with other electric elements of which frequency output is approximately 3 to 12 kHz corresponding to conductivity of the fluid of 0 to 7 S/m. 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.

Pre-cruise sensor calibrations were performed at SBE, Inc., USA. The following coefficients were used in SEASOFT:

**S/N 1203 (primary), 19 April 2005**
- $g = -4.05393563e+00$
- $h = 4.93901550e–01$
- $i = 1.74707654e–05$
- $j = 2.56674141e–05$
- $CP_{cor} = -9.57e–08$ (nominal)
- $CT_{cor} = 3.25e–06$ (nominal)

**S/N 3036 (secondary), 20 January 2005**
- $g = -1.03104164e+01$
- $h = 1.42680631e+00$
- $i = 2.61243729e–04$
- $j = 5.17689837e–05$
- $CP_{cor} = -9.57e–08$ (nominal)
- $CT_{cor} = 3.25e–06$ (nominal)

**S/N 1088 (secondary), 10 March 2005**
- $g = -4.21020783e+00$
- $h = 5.77013782e–01$
- $i = -1.87512042e–04$
- $j = 4.10775826e–05$
- $CP_{cor} = -9.57e–08$ (nominal)
- $CT_{cor} = 3.25e–06$ (nominal)

**S/N 2854 (secondary), 22 June 2004**
- $g = -1.02670783e+00$
Conductivity of a fluid in the cell is expressed as:

\[ C (\text{S/m}) = \frac{g + h \cdot f^2 + i \cdot f^3 + j \cdot f^4}{10(1 + CTcor \cdot t + CPcor \cdot p)} \]

where \( f \) is the instrument frequency (kHz), \( t \) is the water temperature (°C) and \( p \) is the water pressure (dbar). The value of conductivity at salinity of 35, temperature of 15 °C (IPTS-68) and pressure of 0 dbar is 4.2914 S/m.

(4.4) Oxygen (SBE 43)

The SBE 43 oxygen sensor uses a Clark polarographic element to provide in-situ measurements at depths up to 7,000 meters. Calibration stability is improved by an order of magnitude, and pressure hysteresis is largely eliminated in the upper ocean (1,000 m) compared with the previous oxygen sensor (SBE 13). Continuous polarization eliminates wait-time for stabilization after power-up. Signal resolution is increased by on-board temperature compensation. The oxygen sensor is also included in the path of pumped sea water. The oxygen sensor determines dissolved oxygen concentration by counting the number of oxygen molecules per second (flux) that diffuse through a membrane, where the permeability of the membrane to oxygen is a function of temperature and ambient pressure.

Computation of dissolved oxygen in engineering units is done in SEASOFT software. The range for dissolved oxygen is 120 % of surface saturation in all natural waters; nominal accuracy is 2 % of saturation; typical stability is 2 % per 1,000 hours.

Pre-cruise sensor calibrations were performed at SBE, Inc., USA. The following coefficients were used in SEASOFT:

**S/N 0391 (primary), 8 April 2005**
- \( \text{Soc} = 0.3525 \)
- \( \text{Offset} = -0.4761 \)
- \( \text{TCor} = 0.0010 \)
- \( \text{PCor} = 1.3500 - 04 \)

**S/N 0390 (secondary), 8 April 2005**
- \( \text{Soc} = 0.3567 \)
- \( \text{Offset} = -0.4965 \)
- \( \text{TCor} = 0.0013 \)
- \( \text{PCor} = 1.3500 - 04 \)

Oxygen (ml/l) is computed as

\[ \text{Oxygen (ml/l)} = \text{Soc} \cdot (v + \text{Offset}) \cdot e^{(\text{TCor} \cdot t + \text{PCor} \cdot p)} \cdot \text{Oxsat}(t, s) \]

where \( p \) is pressure in dbar, \( t \) is absolute temperature and \( s \) is salinity in psu. \( \text{Oxsat} \) is oxygen saturation value minus the volume of oxygen gas (STP) absorbed from humidity-saturated air.
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 6,800 m.

Temperature is determined by applying an AC excitation to reference resistances and an ultrastable aged thermistor with a drift rate of less than 0.001 °C/year. Each of the resulting outputs is digitized by a 20-bit A/D converter. The reference resistor is a hermetically sealed, temperature-controlled VISHAY. The switches are mercury wetted reed relays with a stable contact resistance. AC excitation and ratiometric comparison using a common processing channel removes measurement errors due to parasitic thermocouples, offset voltages, leakage currents, and gain errors. Maximum power dissipated in the thermistor is 0.5 µwatts, and contributes less than 200 µK of overheat error.

The SBE 35 communicates via a standard RS-232 interface at 300 baud, 8 bits, no parity. The SBE 35 can be used with the SBE 32 Carousel Water Sampler and SBE 911plus CTD system. The SBE 35 makes a temperature measurement each time a bottle fire confirmation is received, and stores the value in EEPROM. Calibration coefficients stored in EEPROM allow the SBE 35 to transmit data in engineering units. Commands can be sent to SBE 35 to provide status display, data acquisition setup, data retrieval, and diagnostic test by using terminal software.

Following the methodology used for standards-grade platinum resistance thermometers (SPRT), calibration of the SBE 35 is accomplished in two steps. The first step is to characterize and capture the non-linear resistance vs temperature response of the sensor. The SBE 35 calibrations are performed at SBE, Inc., in a low-gradient temperature bath and against ITS-90 certified SPRTs maintained at Sea-Bird’s primary temperature metrology laboratory. The second step is frequent certification of the sensor by measurements in thermodynamic fixed-point cells. Triple point of water (TPW) and gallium melt point (GaMP) cells are appropriate for the SBE 35. The SBE 35 resolves temperature in the fixed-point cells to approximately 25 µK. Like SPRTs, slow time drift of the SBE 35 is adjusted by a slope and offset correction to the basic non-linear calibration equation.

Pre-cruise sensor calibrations were performed at SBE, Inc., USA. The following coefficients were stored in EEPROM:

**S/N 0045, 27 October 2002 (1st step: linearization)**

\begin{align*}
a_0 & = 5.84093815 \times 10^{-3} \\
a_1 & = -1.65529280 \times 10^{-3} \\
a_2 & = 2.3794937e-04 \\
a_3 & = -1.32611385 \times 10^{-5} \\
a_4 & = 2.83355203 \times 10^{-7}
\end{align*}

Linearized temperature (ITS-90) is computed according to

\[
\text{Linearized temperature (ITS-90)} = \frac{1}{a_0 + a_1 \cdot \ln(n) + a_2 \cdot \ln^2(n) + a_3 \cdot \ln^3(n) + a_4 \cdot \ln^4(n)} - 273.15
\]

where \( n \) is the instrument output. Then the SBE 35 is certified by measurements in thermodynamic fixed-point cells of the TPW (0.0100 °C) and GaMP (29.7646 °C). Like SPRTs, the slow time drift of the SBE 35 is adjusted by periodic recertification corrections.

**S/N 0045, 6 May 2005 (2nd step: fixed point calibration)**

\begin{align*}
\text{Slope} & = 1.000019 \\
\text{Offset} & = -0.000881
\end{align*}

Temperature (ITS-90) is calibrated according to

\[
\text{Temperature (ITS-90)} = \text{Slope} \times \text{Linearized temperature} + \text{Offset}
\]

The SBE 35 has a time constant of 0.5 seconds. The time required per sample = 1.1 * NCYCLES + 2.7 seconds.

The 1.1 seconds is total time per an acquisition cycle. NCYCLES is the number of acquisition cycles per sample. The 2.7 seconds is required for converting the measured values to temperature and storing average in EEPROM. Root mean square (rms) temperature noise for a SBE 35 in a Triple Point of Water cell is typically expressed as \( 82 / \text{NCYCLES}^{0.5} \) in µK. In this cruise NCYCLES was set to 4 and the rms noise is estimated to be 0.04 m°C.

When using the SBE 911 system with the SBE 35, the deck unit receives incorrect signal from the under water unit for confirmation of firing bottle #16. In order to correct the signal, a module (Yoshi Ver. 1, EMS Co. Ltd.,...
JAPAN) was used between the under water unit and the deck unit.

Time drift of the SBE 35 based on the fixed point calibrations is shown in Figure 3.1.5.

![Figure 3.1.5: SBE35 (S/N 0045) time drift based on laboratory fixed point calibrations (triple point of water, TPW and gallium melt point, GaMP) performed by SBE, Inc.](image)

**Figure 3.1.5.**, SBE35 (S/N 0045) time drift based on laboratory fixed point calibrations (triple point of water, TPW and gallium melt point, GaMP) performed by SBE, Inc.

### 4.6 Altimeter

Benthos PSA-916T Sonar Altimeter (Benthos, Inc., USA) 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. The PSA-916T is the same as the standard PSA-916 Sonar Altimeter except that it is housed in a corrosion-resistant titanium pressure case. It is O-ring-sealed and rated for operation in water depths up to 10,000 meters. In this unit, a 250 microseconds pulse at 200 kHz is transmitted 5 times in a second. The PSA-916T uses the nominal speed of sound of 1,500 m/s. Thus the unit itself, neglecting variations in the speed of sound, can be considered accurate to 5% or 0.1 meter, whichever is greater. In the PSA-916T the jitter of the detectors is approximately 5 microseconds or ± 0.4 cm total distance. Since the total travel time is divided by two, the jitter error is ± 0.2 cm.

The following scale factors were used in SEASOFT:

\[
\text{S/N 1157}
\]

\[
\begin{align*}
FSVolt \times 300 / \text{FSRange} &= 15 \\
\text{Offset} &= 0.0
\end{align*}
\]

### 4.7 Fluorometer

The Seapoint Chlorophyll Fluorometer (Seapoint sensors, Inc., USA) is a high-performance, low power instrument to provide in-situ measurements of chlorophyll-a at depths up to 6,000 meters. 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.

The following coefficients were used in SEASOFT:

\[
\text{S/N 2579}
\]

\[
\begin{align*}
\text{Gain} &= 30 \\
\text{Offset} &= 0.0
\end{align*}
\]

Chlorophyll-a concentration is computed as

\[
\text{Chlorophyll-a (µg/l)} = \frac{\text{Voltage} \times 30}{\text{Gain}} + \text{Offset}
\]

### 5 Data collection and processing

#### 5.1 Data collection

CTD measurements were made by using a SBE 9plus equipped with two pumped temperature-conductivity (TC) sensors. The TC pairs were monitored to check drift and shifts by examining the differences between the two pairs. A dissolved oxygen sensor was placed between the conductivity sensor module and the pump. Auxiliary sensors included Deep Ocean Standards Thermometer, altimeter and fluorometer. The SBE 9plus (sampling rate of 24 Hz)
was mounted horizontally in a 36-position carousel frame. CTD system was powered on at least two minutes in advance of the operation and was powered off at least two minutes after the operation in order to acquire pressure data on the ship’s deck.

The package was lowered into the water from the starboard side and held 10 m beneath the surface for about one minute 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 then the package was stopped in order to operate the heave compensator of the crane. The package was lowered again at a rate of 1.2 m/s to the bottom. The position of the package relative to the bottom was monitored by the altimeter reading. Also the bottom depth was monitored by the SEABEAM multi-narrow beam sounding on board. For the up cast, the package was lifted at a rate of 1.2 m/s except for bottle firing stops. At each bottle firing stops, the bottle was fired after waiting from the stop for 30 seconds and the package was stayed 5 seconds for measurement of the Deep Ocean Standards Thermometer. At 200 m from the surface, the package was stopped in order to stop the heave compensator of the crane.

Water samples were collected using a 36-bottle SBE 32 Carousel Water Sampler with 12-litre Niskin-X bottles. Before a cast taken water for CFCs, the 36-bottle frame and Niskin-X bottles were wiped with acetone.

The SBE 11plus deck unit received the data signal from the CTD. Digitized data were forwarded to a personal computer running the SEASAVE data acquisition software. Temperature, conductivity, salinity, oxygen and descent rate profiles were displayed in real-time with the package depth and altimeter reading. Differences in temperature salinity and oxygen between primary and secondary sensor were also displayed in order to monitor the status of the sensors.

**Data acquisition software**

SBE, Inc., SEASAVE-Win32, version 5.27b

### (5.2) Data collection problems

At station P10N_142, bottle #1 did not fire at the beginning of the up cast. The first cast was aborted and Y-cable was replaced. At station P10N_137, the primary temperature showed abnormal values at depths between 450 and 430 dbar in the up cast. The connecting cable and connector for the primary temperature sensor was checked and cleaned.

At station P10N_122, the primary oxygen sensor was replaced because the difference between the sensor output and the bottle oxygen was gradually becoming greater (40 µmol/kg near the bottom).

At station P10N_113, the primary temperature data was slightly noisy during up cast. And at station P10N_112, the primary temperature signal was lost near the bottom. The connecting cable for the temperature sensor was replaced after the cast.

At station P10N_101 and 100, the secondary temperature and conductivity were very noisy from the up cast of P10N_101 because of something in the secondary TC duct. The TC duct was flushed well after the cast.

At station P10_62, the CTD signal was lost at 1,270 dbar in the down cast and the cast was aborted. The second cast was carried out after re-connecting the armored cable and pigtail.

At station P10_53, the secondary conductivity was abnormally biased near the bottom. The conductivity sensor was replaced after the cast.

At station P10_27, the secondary conductivity was abnormally biased near the bottom. The conductivity sensor was replaced after the cast.

### (5.3) Data processing

SEASOFT consists of modular menu driven routines for acquisition, display, processing, and archiving of oceanographic data acquired with SBE equipment, and is designed to work with a compatible personal computer. Raw data are acquired from instruments and are stored as unmodified data. The conversion module DATCNV uses the instrument configuration and calibration coefficients to create a converted engineering unit data file that is operated on by all SEASOFT post processing modules. Each SEASOFT module that modifies the converted data file adds proper information to the header of the converted file permitting tracking of how the various oceanographic parameters were obtained. The converted data is stored in rows and columns of ASCII numbers. The last data column is a flag field used to mark scans as good or bad.

The followings are the SEASOFT data processing module sequence and specifications used in the reduction of CTD data in this cruise.
**Data processing software**

SBE, Inc., SEASOFT-Win32, version 5.27b

DATCNV converted the raw data to scan number, pressure, depth, temperatures, conductivities, oxygen voltage, descent rate, altitude and fluorescence. 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 seconds.

ROSSUM created a summary of the bottle data. The bottle position, date, time were output as the first two columns. Scan number, pressure, depth, temperatures, conductivities, oxygen voltage, descent rate, altitude and fluorescence were averaged over 4.4 seconds. And salinity, potential temperature, density ($\sigma_{\theta}$) and oxygen were computed.

ALIGNCTD converted the time-sequence of conductivity and oxygen 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 3,000-rpm pump, 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 oxygen sensor output (oxygen voltage) relative to the temperature.

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 all variables.

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 a median filter to remove spikes in the Fluorometer data. A median value was determined from a window of 49 scans.

SECTION selected a time span of data based on scan number in order to reduce a file size. The minimum number was set to be the start time when the CTD package was beneath the sea-surface after activation of the pump. The maximum number was set to be the end time when the package came up from the surface. Data for estimation of the CTD pressure drift were prepared before SECTION.

LOOPEDIT marked scans where the CTD was moving less than the minimum velocity of 0.0 m/s (traveling backwards due to ship roll).

DERIVE was used to compute oxygen.

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 could exist every dbar.

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

SPLIT was used to split data into the down cast and the up cast.

Remaining spikes in the salinity data were manually eliminated for the raw data. When number of data in the 1-dbar-pressure bin was less than 10, the data of the bin was not used. For remaining spikes in the Fluorometer data near surface, quality flags of the Fluorometer data were set to 4. Remaining spikes in the oxygen data were eliminated for a 1-dbar averaged data when the difference between original data and low-pass (7-dbar median) filtered data was greater than or equal to 0.003 (voltage) at the pressure level greater or equal to 1,200 dbar (1,150 dbar for station X03). The data gap over 1-dbar was linearly interpolated with a quality flag of 6.
(6) Post-cruise calibration

(6.1) Pressure

The CTD pressure sensor offset in the period of the cruise is estimated from the pressure readings on the ship deck. For best results the Paroscientific sensor has to be powered for at least 10 minutes before the operation and carefully temperature equilibrated. However, CTD system was powered only several minutes before the operation at most of stations. In order to get the calibration data for the pre- and post-cast pressure sensor drift, the CTD deck pressure is averaged over first and last two minutes, respectively. Then the atmospheric pressure deviation from a standard atmospheric pressure (14.7 psi) is subtracted from the CTD deck pressure. 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 Figure 3.1.6.

The CTD pressure sensor offset is estimated from the deck pressure obtained above. Mean of the pre- and the post-casts data over the whole period gave an estimation of the pressure sensor offset from the pre-cruise calibration. Mean residual pressure between the dead weight piston gauge and the calibrated CTD data at 0 dbar of the pre-cruise calibration is subtracted from the mean deck pressure. Offset of the pressure data is estimated to be −0.40 dbar (Table 3.1.1). So the post-cruise correction of the pressure data is not deemed necessary for the pressure sensor.

Table 3.1.1. Offset of the pressure data. Mean and standard deviations are calculated from time series of the average of the pre- and the post-cast deck pressures.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Mean deck pressure (dbar)</th>
<th>Standard deviation (dbar)</th>
<th>Residual pressure (dbar)</th>
<th>Estimated offset (dbar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0677</td>
<td>−0.42</td>
<td>0.05</td>
<td>−0.02</td>
<td>−0.40</td>
</tr>
</tbody>
</table>

(6.2) Temperature

The CTD temperature sensor (SBE 3) is made with a glass encased thermistor bead in a needle. The needle protects the thermistor from seawater. If the thermistor bead is slightly large of specification it receives mechanical stress when the needle is compressed at high pressure (Budeus and Schneider, 1998). The pressure sensitivity for a SBE 3 sensor is usually less than +2 m°C / 6000 dbar. It is somewhat difficult to measure this effect in the laboratory and it the difficulty is one of the primary reasons to use the SBE 35 at sea for critical work. Also SBE 3 measurements may be affected by viscous heating (about +0.5 m°C) that occurs in a TC duct and does not occur for un-pumped SBE 35 measurements (Larson and Pederson, 1996). Furthermore, the SBE 35 calibrations have some uncertainty (about 0.2 m°C) and SBE 3 calibrations have some uncertainty (about 1 m°C). So the practical corrections for CTD temperature data can be made by using a SBE 35, correcting the SBE 3 to agree with the SBE 35 (a linear pressure correction, a viscous heating correction and an offset for drift and/or calibration uncertainty).

Post-cruise sensor calibration for the SBE 35 was performed at SBE, Inc., USA.

S/N 0045, 15 August 2005 (2nd step: fixed point calibration)

Slope = 1.000011
Offset = −0.000973

Figure 3.1.6. Time series of the CTD deck pressure. Pink dot indicates atmospheric pressure anomaly. Blue and green dots indicate pre- and post-cast deck pressures, respectively. Red dot indicates an average of the pre- and the post-cast deck pressures.
Offset of the SBE 35 data from the pre-cruise calibration are estimated to be 0.1 m°C for temperature less than 4 °C. So the post-cruise correction of the SBE 35 temperature data is not deemed necessary for the SBE 35. The discrepancy between the CTD temperature and the SBE 35 is considered to be a function of pressure and time. Effect of the viscous heating is assumed to be constant. Since the pressure sensitivity is thought to be constant in time at least during observation period, the CTD temperature is calibrated as

\[
\text{Calibrated temperature} = T - (c_0 \cdot P + c_1 \cdot t + c_2)
\]

where T is CTD temperature in °C, P is pressure in dbar, t is time in days from pre-cruise calibration date of CTD temperature and c_0, c_1, and c_2 are calibration coefficients. The best fit sets of coefficients are determined by minimizing the sum of absolute deviation from the SBE 35 data. The MATLAB® function FMINSEARCH is used to determine the sets. The FMINSEARCH uses the simplex search method (Lagarias et al., 1998). This is a direct search method that does not use numerical or analytic gradients.

The calibration is performed for the primary and secondary temperature data. The CTD data created by the software module ROSSUM are used. The deviation of CTD temperature from the SBE 35 temperature at depth shallower than 2,000 dbar is large for determining the coefficients with sufficient accuracy since the vertical temperature gradient is too large in the regions. So the coefficients are determined using the data for the depth deeper than 1,950 dbar.

The number of data used for the calibration and the mean absolute deviation from the SBE 35 are listed in Table 3.1.2 and the calibration coefficients are listed in Table 3.1.3. The results of the post-cruise calibration for the CTD temperature are summarized in Table 3.1.4 and shown in Figure 3.1.7 and 3.1.8.

Basically, the secondary temperature data is used for the dataset. For the station P10N_101, P10N_100, P10_53 and P10_27, the primary temperature data is used instead of the secondary temperature data because the quality of the secondary conductivity data at these stations was bad.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Number of data</th>
<th>ADEV (m°C)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1464</td>
<td>1586</td>
<td>0.10</td>
<td>for P10N_101, P10N_100, P10_53 and P10_27</td>
</tr>
<tr>
<td>1525</td>
<td>1583</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1.2. Number of data used for the calibration (pressure >= 1,950 dbar) and mean absolute deviation (ADEV) between the CTD temperature and the SBE 35.

<table>
<thead>
<tr>
<th>S/N</th>
<th>c_0 (°C/dbar)</th>
<th>c_1 (°C/day)</th>
<th>c_2 (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1464</td>
<td>-1.0013e-7</td>
<td>2.4017e-6</td>
<td>0.56e-3</td>
</tr>
<tr>
<td>1525</td>
<td>-7.9037e-9</td>
<td>2.8765e-6</td>
<td>0.29e-3</td>
</tr>
</tbody>
</table>

Table 3.1.3. Calibration coefficients for the CTD temperature sensors.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Pressure &gt;= 1,950 dbar</th>
<th>Pressure &lt; 1,950 dbar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Num</td>
<td>Mean (m°C)</td>
</tr>
<tr>
<td>1464</td>
<td>1586</td>
<td>0.00</td>
</tr>
<tr>
<td>1525</td>
<td>1583</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 3.1.4. 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 1,950 dbar. Number of data used is also shown.
Figure 3.1.7. Difference between the CTD temperature (primary) and the Deep Ocean Standards thermometer (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.

Figure 3.1.8. Same as Figure 3.1.7, but for the secondary CTD temperature.
(6.3) Salinity

The discrepancy between the CTD salinity and the bottle salinity is considered to be a function of conductivity and pressure. The CTD salinity is calibrated as

\[ \text{Calibrated salinity} = S - (c_0 \cdot P + c_1 \cdot C + c_2 \cdot C \cdot P + c_3) \]

where \( S \) is CTD salinity, \( P \) is pressure in dbar, \( C \) is conductivity in S/m and \( c_0, c_1, c_2 \), and \( c_3 \) are calibration coefficients. The best fit sets of coefficients are determined by minimizing the sum of absolute deviation with a weight from the bottle salinity data. The MATLAB® function FMINSEARCH is used to determine the sets. The weight is given as a function of vertical salinity gradient and pressure as

\[ \text{Weight} = \min(4, \exp(\log(4) \cdot \text{Grad} / \text{Grad})) \cdot \min(4, \exp(\log(4) \cdot P / \text{PR}^2)) \]

where Grad is vertical salinity gradient in PSU dbar\(^{-1}\), \( P \) is pressure in dbar. Gr and PR are threshold of the salinity gradient (0.5 mPSU dbar\(^{-1}\)) and pressure (1,000 dbar), respectively. When salinity gradient is small (large) and pressure is large (small), the weight is large (small) at maximum (minimum) value of 16 (1). The salinity gradient is calculated using up-cast CTD salinity data. The up-cast CTD salinity data is low-pass filtered with a 3-point (weights are 1/4, 1/2, 1/4) triangle filter before the calculation.

The calibration is performed for the salinity derived from the following conductivity sensor.

- Secondary (S/N 3036): from P10N_143 to P10_54 except for P10N_101 and P10N_100
- Secondary (S/N 1088): from P10_52 to P10_28
- Secondary (S/N 2854): from P10_26 to P10_1
- Primary (S/N 1203): for P10N_101, P10N_100, P10_53 and P10_27

The CTD data created by the software module ROSSUM are used after the post-cruise calibration for the CTD temperature. On stations P10N_101, P10N_100, P10_53 and P10_27, data quality of the secondary conductivity sensor was bad, so the data from the primary conductivity sensor are used for the stations.

The coefficients are determined for some groups of the CTD station. The results of the post-cruise calibration for the CTD salinity are summarized in Table 3.1.5 and shown in Figure 3.1.9. And the calibration coefficients and the number of the data (Num) used for the calibration are listed in Table 3.1.6.

<table>
<thead>
<tr>
<th>Pressure &gt;= 1,000 dbar</th>
<th>Pressure &lt; 1,000 dbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num</td>
<td>Mean (mPSU)</td>
</tr>
<tr>
<td>2031</td>
<td>-0.03</td>
</tr>
</tbody>
</table>
Table 3.1.6. Calibration coefficients for the CTD salinity.

<table>
<thead>
<tr>
<th>Stations (Num)</th>
<th>$c_0$</th>
<th>$c_1$</th>
<th>$c_2$</th>
<th>$c_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>143_1-122_1</td>
<td>1.0131034690e–5</td>
<td>8.0275830498e–4</td>
<td>-3.1419321824e–6</td>
<td>-1.7267523622e–4</td>
</tr>
<tr>
<td>(598)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>121_1-102_1</td>
<td>1.1573101209e–6</td>
<td>-5.5651332935e–4</td>
<td>-4.1004021024e–7</td>
<td>4.8048881814e–3</td>
</tr>
<tr>
<td>(709)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101_1-100_1,</td>
<td>7.0963418115e–7</td>
<td>-1.4372272016e–3</td>
<td>-1.9540013620e–7</td>
<td>6.9910914220e–3</td>
</tr>
<tr>
<td>53_1, 27_1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(134)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>99_1-61_1</td>
<td>-7.2653193556e–7</td>
<td>-4.6533749916e–4</td>
<td>1.6408648275e–7</td>
<td>3.6992027960e–3</td>
</tr>
<tr>
<td>(695)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60_1-54_1</td>
<td>4.2743744355e–6</td>
<td>-1.0727071488e–3</td>
<td>-1.3910765762e–6</td>
<td>5.055686130e–3</td>
</tr>
<tr>
<td>(228)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52_1-40_1</td>
<td>-1.9442243171e–6</td>
<td>-2.9304615120e–3</td>
<td>6.6566837298e–7</td>
<td>1.0095656997e–2</td>
</tr>
<tr>
<td>(436)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39_1-28_1</td>
<td>-7.0071602987e–6</td>
<td>-3.1405026102e–3</td>
<td>2.2878224338e–6</td>
<td>1.0159646236e–2</td>
</tr>
<tr>
<td>(334)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26_1-1_1</td>
<td>-7.0377497246e–6</td>
<td>-2.4744338608e–3</td>
<td>2.1748120985e–6</td>
<td>1.0327699240e–2</td>
</tr>
<tr>
<td>(578)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1.9. Difference between the CTD salinity and the bottle salinity. Blue and red dots indicate before and after the post-cruise calibration using the bottle salinity data, respectively. Lower two panels show histogram of the difference after the calibration.
(6.4) Oxygen

The CTD oxygen is calibrated using the oxygen model (see 3.1.3(4)) as:

\[ \text{Calibrated oxygen (ml/l)} = \{(Soc + dSoc) \times \{v + offset + doffset\} \times \exp\{(TCor + dTCor) \times t + (PCor + dPCor) \times p\}\} \]

where \( p \) is pressure in dbar, \( t \) is absolute temperature and \( s \) is salinity in psu. Oxsat is oxygen saturation value minus the volume of oxygen gas (STP) absorbed from humidity-saturated air (see 3.1.3(4)). Soc, offset, TCor and PCor are the pre-cruise calibration coefficients (see 3.1.3(4)), and dSoc, doffset, dTCor and dPCor are calibration coefficients.

The best fit sets of coefficients are determined by minimizing the sum of absolute deviation with a weight from the bottle oxygen data. The MATLAB® function FMINSEARCH is used to determine the sets. The weight is given as a function of vertical oxygen gradient and pressure as:

\[ \text{Weight} = \min\{\text{min}(4, \exp(\text{log}(4) \times Gr / Grad)), \text{min}(4, \exp(\text{log}(4) \times P^2 / PR^2))\} \]

where Grad is vertical oxygen gradient in µmol kg \(^{-1}\) dbar \(^{-1}\), \( P \) is pressure in dbar. Gr and PR are threshold of the oxygen gradient (0.3 µmol kg \(^{-1}\) dbar \(^{-1}\)) and pressure (1,000 dbar), respectively. When oxygen gradient is small (large) and pressure is large (small), the weight is large (small) at maximum (minimum) value of 16 (1). The oxygen gradient is calculated using up-cast CTD oxygen data. The up-cast CTD oxygen data is low-pass filtered with a 3-point (weights are 1/4, 1/2, 1/4) triangle filter before the calculation.

The calibration is basically performed for the output from secondary oxygen sensor. On stations P10N_101 and P10N_100, data quality of the secondary oxygen sensor were bad, so the data from the primary oxygen sensor are used for the stations. The down-cast CTD data sampled at same density of the up-cast CTD data created by the software module ROSSUM are used after the post-cruise calibration for the CTD temperature and salinity.

The coefficients are basically determined on each station. Some stations, especially on shallow stations, are grouped for determining the calibration coefficients. The results of the post-cruise calibration for the CTD oxygen are summarized in Table 3.1.7 and shown in Figure 3.1.10. And the calibration coefficients and number of the data used for the calibration are listed in Table 3.1.8.

### Table 3.1.7. Difference between the CTD oxygen and the bottle oxygen after the post-cruise calibration. Mean and standard deviation (Sdev) are calculated for the data below and above 1,000 dbar. Number of data used is also shown.

<table>
<thead>
<tr>
<th>Pressure &gt;= 1,000 dbar</th>
<th>Pressure &lt; 1,000 dbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num</td>
<td>Mean</td>
</tr>
<tr>
<td>(µmol/kg)</td>
<td>(µmol/kg)</td>
</tr>
<tr>
<td>2091</td>
<td>–0.01</td>
</tr>
</tbody>
</table>

### Table 3.1.8. Calibration coefficients for the CTD oxygen.

<table>
<thead>
<tr>
<th>Stations (Num)</th>
<th>dSoc</th>
<th>dTCor</th>
<th>dPCor</th>
<th>doffset</th>
</tr>
</thead>
<tbody>
<tr>
<td>143_1-135_1(150)</td>
<td>8.4629646531e–3</td>
<td>5.8573110490e–5</td>
<td>8.5929128792e–6</td>
<td>–2.529685384e–2</td>
</tr>
<tr>
<td>134_1 (33)</td>
<td>1.1267442718e–2</td>
<td>–6.2548916427e–3</td>
<td>3.5064120727e–6</td>
<td>–9.419492175e–4</td>
</tr>
<tr>
<td>133_1 (35)</td>
<td>1.6126510125e–2</td>
<td>3.5398495888e–4</td>
<td>2.1736462574e–6</td>
<td>–1.462520328e–2</td>
</tr>
<tr>
<td>132_1 (34)</td>
<td>2.3848796038e–2</td>
<td>–7.2897960077e–4</td>
<td>1.4777271150e–7</td>
<td>–1.7971132206e–2</td>
</tr>
<tr>
<td>131_1-130_1(70)</td>
<td>2.5787931229e–2</td>
<td>–1.1510003784e–3</td>
<td>1.750494703e–6</td>
<td>–2.5297499910e–2</td>
</tr>
<tr>
<td>129_1 (35)</td>
<td>2.5699254255e–2</td>
<td>–2.4457679187e–3</td>
<td>3.1376007240e–6</td>
<td>–2.8137678768e–2</td>
</tr>
<tr>
<td>128_1 (36)</td>
<td>2.7101839015e–2</td>
<td>–5.3160010276e–3</td>
<td>1.0471669748e–6</td>
<td>–2.1112137342e–2</td>
</tr>
<tr>
<td>127_1-124_1(140)</td>
<td>3.2771370687e–2</td>
<td>–1.419490742e–3</td>
<td>4.3317721487e–4</td>
<td>–3.126432013e–2</td>
</tr>
<tr>
<td>123_1 (34)</td>
<td>1.3461831314e–2</td>
<td>1.2534516726e–3</td>
<td>3.4978137387e–6</td>
<td>–1.1130414739e–2</td>
</tr>
<tr>
<td>122_1-121_1(67)</td>
<td>2.4505139384e–2</td>
<td>–7.6774993155e–6</td>
<td>4.0666037955e–6</td>
<td>–1.9391470346e–2</td>
</tr>
<tr>
<td>120_1-118_1(106)</td>
<td>2.4393648000e–2</td>
<td>3.8668328581e–4</td>
<td>4.8139225402e–6</td>
<td>–2.2964168413e–2</td>
</tr>
<tr>
<td>117_1 (36)</td>
<td>6.4297501230e–2</td>
<td>–6.0748102232e–3</td>
<td>1.2321533791e–4</td>
<td>–4.3578232477e–2</td>
</tr>
<tr>
<td>116_1-115_1(69)</td>
<td>6.1728950413e–2</td>
<td>–2.4236972142e–3</td>
<td>8.4116664417e–6</td>
<td>–2.8152202106e–2</td>
</tr>
<tr>
<td>114_1 (36)</td>
<td>7.0360855390e–2</td>
<td>–1.9473306036e–3</td>
<td>7.1904905368e–6</td>
<td>–3.437530578e–2</td>
</tr>
<tr>
<td>113_1 (36)</td>
<td>5.7514523160e–2</td>
<td>–1.3251685263e–3</td>
<td>1.1702324658e–5</td>
<td>–2.8436450647e–2</td>
</tr>
<tr>
<td>112_2 (36)</td>
<td>6.1225526921e–2</td>
<td>–1.1296247021e–3</td>
<td>1.5631766694e–5</td>
<td>–2.7485442452e–2</td>
</tr>
</tbody>
</table>
Figure 3.1.10. Difference between the CTD oxygen and the bottle oxygen. Blue and red dots indicate before and after the post-cruise calibration using the bottle oxygen data, respectively. Lower two panels show histogram of the difference after the calibration.

References


(http://www.seabird.com/technical_references/paperindex.htm)
3.2 Salinity

13 October 2006

(1) Personnel

Takeshi Kawano (JAMSTEC)
Fujio Kobayashi (MWJ)
Kenichi Katayama (MWJ)
Tatsuya Tanaka (MWJ)

(2) Objectives

Measurement of bottle salinities in order to calibrate CTD salinities and to identify leaking bottles.

(3) Instrument and Method

(3.1) Salinity Sample Collection

The bottles in which the salinity samples are collected and stored are 250 ml Phoenix brown glass bottles with
screw caps. Each bottle was rinsed three times with sample water and was filled to the shoulder of the bottle. The
caps were also thoroughly rinsed. Salinity samples were stored for about 12 hours in the same laboratory as the
salinity measurement was made.

(3.2) Instruments and Method

The salinity analysis was carried out on Guildline Autosal salinometers model 8400B (S/N 62556), which were
modified by addition of an Ocean Science International peristaltic-type sample intake pump and two Guildline
platinum thermometers model 9450. One thermometer monitored an ambient temperature and the other monitored a
bath temperature. The resolution of the thermometers was 0.001 °C. The measurement system was almost same as
Aoyama et al (2003). The salinometer was operated in a ship's laboratory air-conditioned at a bath temperature of 24
°C. Ambient temperature varied from approximately 22 °C to 24 °C, while bath temperature is very stable and varied
within ± 0.002 °C on rare occasion. A measure of a double conductivity ratio of a sample is taken as a median of
thirty-one readings. Data collection was started after 5 seconds and it took about 10 seconds to collect 31 readings by
a personal computer. Data were sampled for the sixth and the seventh filling of the cell. In case the difference in the
double conductivity ratio between this two fillings was smaller than 0.00003, 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). If the difference was greater than or equal to 0.00003, we measured the eighth filling of the cell. In
case the double conductivity ratio of the eighth filling did not satisfy the criteria above, we measured the ninth and the
tenth filling of the cell and the median of the double conductivity ratios of these five fillings are used to calculate
the bottle salinity.

The measurement was conducted for about 16 hours per day (typically from 7:00 to 23:00) and the cell was
cleaned with ethanol or soap or both after the measurement of the day.

(3.3) Preliminary Result

Standard Seawater

Standardization control was set to 491 and all the measurements were done by this setting. During the whole
measurement, STANDBY was 5509 ± 0001 and ZERO was 0.00001. We used IAPSO Standard Seawater batch P145
whose conductivity ratio was 0.99981 (double conductivity ratio is 1.99962) as the standard for salinity. We
measured 177 ampoules of P145. There were 5 bad bottles whose conductivities are extremely high or low. Data of
these 5 bottles are not taken into consideration hereafter.

Fig.3.2.1 shows the history of double conductivity ratio of the Standard Seawater batch P145. During this cruise,
we did flushing the cell twice for cleaning using ultrasonic washing machine. The average of double conductivity
ratio from Stn.143 to Stn.071 was 1.99962 and the standard deviation was 0.00001, which is equivalent to 0.0002 in
salinity. The average from Stn.070 to Stn.023 was 1.99963 and the standard deviation was 0.00001. We reduce
0.00001 to the measured double conductivity ratio during this period. The average of double conductivity ratio from
Stn.022 to Stn.001 was 1.99962 and the standard deviation was 0.00001, which is equivalent to 0.0002 in salinity.
Sub-Standard Seawater

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

Replicate and Duplicate Samples

We took 666 pairs of replicate samples and 55 pairs of duplicate samples. Figure 3.2.2 (a) and (b) show the histogram of the absolute difference among replicate samples and among duplicate ones, respectively. There were six bad measurements and 18 questionable measurements in replicate samples and six questionable measurements in duplicate samples. Excluding these bad and questionable measurements, the standard deviation of the absolute deference of 642 pairs of replicate samples was 0.0002 in salinity and that of 48 pairs of duplicate samples was 0.0002 in salinity. The results of replicate samples were averaged and flagged as 6 in the seafile.
Figure 3.2.2 (b). The histogram of the absolute difference between duplicate samples.

References


3.3 Oxygen

17 October 2006

(1) Personnel

Ikuo KANEKO (JAMSTEC)
Yuichiro KUMAMOTO (JAMSTEC)
Takayoshi SEIKE (MWJ)
Ai YASUDA (MWJ)
Kimiko NISHIJIMA (MWJ)

(2) Objectives

Dissolved oxygen is a significant tracer for the ocean circulation study. Recent studies in the North Pacific indicated that dissolved oxygen concentration in intermediate layers decreased in basin wide scale during the past decades. The causes of the decrease, however, are still unclear. During MR05-02, we measured dissolved oxygen concentration from surface to bottom layers at all hydrocast stations. The stations from 29°N to 4°S reoccupied WHP P10 stations in 1993. Our purpose is to evaluate decadal change of dissolved oxygen in the western Pacific.

(3) Regent

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)
CSK standard of potassium iodate: Lot ASE8280, Wako Pure Chemical Industries Ltd., 0.0100N

(4) Instruments

Burette for sodium thiosulfate;
APB-510 manufactured by Kyoto Electronic Co. Ltd. / 10 cm³ of titration vessel
Burette for potassium iodate;
APB-410 manufactured by Kyoto Electronic Co. Ltd. / 20 cm³ of titration vessel
Detector; Automatic photometric titrator manufactured, Kimoto Electronic Co. Ltd

(5) Seawater Sample

Following procedure is based on a determination method in the WHP Operations Manual (Dickson, 1996). Seawater samples were collected from Niskin sampler bottles attached to the CTD-system. Seawater for bottle oxygen measurement was transferred from the Niskin sampler bottle to a volume calibrated glass flask (ca. 100 cm³). Three times volume of the flask of seawater was overflowed. Sample temperature was measured by a thermometer during the overflow. Then two reagent solutions (Reagent I, II) of 0.5 cm³ each were added immediately to 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 and throughout. After the precipitate settled at least halfway down the flask, the flask was vigorously 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 to the sample flask and stirring began. Samples were titrated with sodium thiosulfate solution whose molarity was determined by potassium iodate solution (section 3.3.6). Temperature of sodium thiosulfate during titration was recorded by a thermometer. During this cruise we measured dissolved oxygen concentration using two sets of the titration apparatus, DOT-1 and DOT-2. Dissolved oxygen concentration (µmol kg⁻¹) was calculated by sample temperature during the sampling, CTD salinity, flask volume, and titrated volume of the sodium thiosulfate solution.
(7) Standardization

Concentration of sodium thiosulfate titrant (ca. 0.025M) was determined by potassium iodate solution. Pure potassium iodate was dried in an oven at 130 °C. 1.7835 g potassium iodate accurately weighed. An accurately weighted 1.7835 g of potassium iodate 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 a 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 gave the molarity of the sodium thiosulfate titrant. Table 3.3.1 shows result of the standardization during this cruise. Error (C.V.) of the each standardization was less than 0.08 % (n = 5).

(8) Determination of the blank

Table 3.3.1. Results of the standardization and the blank determinations during MR05-02.

<table>
<thead>
<tr>
<th>Date (UTC)</th>
<th>KI03 bottle</th>
<th>DOT-1 (cm³)</th>
<th>Na2S2O3 E.P. blank</th>
<th>DOT-2 (cm³)</th>
<th>Na2S2O3 E.P. blank</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005/5/26</td>
<td>20050620-01</td>
<td>3.959 - 0.006</td>
<td>20050523-2</td>
<td>3.961 - 0.011</td>
<td>135-143</td>
</tr>
<tr>
<td>2005/5/28</td>
<td>20050620-02</td>
<td>3.960 - 0.005</td>
<td>20050523-2</td>
<td>3.961 - 0.008</td>
<td>131-134</td>
</tr>
<tr>
<td>2005/5/29</td>
<td>20050620-03</td>
<td>3.957 - 0.008</td>
<td>20050523-4</td>
<td>3.961 - 0.011</td>
<td>127-130</td>
</tr>
<tr>
<td>2005/5/30</td>
<td>20050620-04</td>
<td>3.960 - 0.006</td>
<td>20050523-4</td>
<td>3.964 - 0.008</td>
<td>123-126</td>
</tr>
<tr>
<td>2005/5/31</td>
<td>20050620-05</td>
<td>3.959 - 0.006</td>
<td>20050529-2</td>
<td>3.961 - 0.009</td>
<td>119-122</td>
</tr>
<tr>
<td>2005/6/2</td>
<td>20050620-06</td>
<td>3.959 - 0.006</td>
<td>20050529-2</td>
<td>3.959 - 0.009</td>
<td>115-118</td>
</tr>
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<td>3.959 - 0.007</td>
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</tr>
<tr>
<td>2005/6/4</td>
<td>20050620-08</td>
<td>3.958 - 0.006</td>
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<td>3.961 - 0.009</td>
<td>107-110</td>
</tr>
<tr>
<td>2005/6/5</td>
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<td>3.954 - 0.007</td>
<td>20050603-2</td>
<td>3.957 - 0.011</td>
<td>103-106</td>
</tr>
<tr>
<td>2005/6/6</td>
<td>20050620-14</td>
<td>3.956 - 0.006</td>
<td>20050603-2</td>
<td>3.956 - 0.011</td>
<td>99-102</td>
</tr>
<tr>
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<td>20050620-15</td>
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<td>3.958 - 0.011</td>
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<tr>
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<tr>
<td>2005/6/10</td>
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<td>3.961 - 0.008</td>
<td>20050609-2</td>
<td>3.960 - 0.011</td>
<td>67</td>
</tr>
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<td>3.955 - 0.010</td>
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<td>20050609-4</td>
<td>3.954 - 0.009</td>
<td>58-61</td>
</tr>
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</tr>
<tr>
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<td>20050613-2</td>
<td>3.953 - 0.009</td>
<td>50-53</td>
</tr>
<tr>
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<td>3.953 - 0.006</td>
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<td>20050620-27</td>
<td>3.953 - 0.008</td>
<td>20050613-4</td>
<td>3.954 - 0.010</td>
<td>42,404,44,45</td>
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<td>20050613-4</td>
<td>3.954 - 0.008</td>
<td>36-41</td>
</tr>
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<td>3.962 - 0.010</td>
<td>31-35</td>
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<td>3.960 - 0.007</td>
<td>20050618-2</td>
<td>3.962 - 0.010</td>
<td>27-30</td>
</tr>
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<td>20050618-4</td>
<td>3.962 - 0.010</td>
<td>23-26</td>
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<td>20050618-4</td>
<td>3.966 - 0.010</td>
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<td>3.957 - 0.003</td>
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<td>3.957 - 0.009</td>
<td>20050622-4</td>
<td>3.961 - 0.009</td>
<td>14</td>
</tr>
</tbody>
</table>

(9) Reagent blank

The blank determined in the section 3.3.7, pure water blank (Vb,water) can be represented by equation 1,

\[ V_{b,water} = V_{b,ep} + V_{b,reg} \]  

(1)
where

\[ V_{\text{bulk, ep}} = \text{blank due to differences between the measured end-point and the equivalence point}; \]

\[ V_{\text{bulk, reg}} = \text{blank due to oxidants or reductants in the reagent}. \]

Here, the reagent blank \( V_{\text{bulk, reg}} \) was determined by following procedure. 1 cm\(^3\) of the standard potassium iodate solution and 100 cm\(^3\) of deionized water were added to two flasks. 1 cm\(^3\) of sulfuric acid solution and 0.5 cm\(^3\) of pickling reagent solution II and I each were added to the first flask in order. Then to the second flask, two times volume of the reagents (2 cm\(^3\) of sulfuric acid solution, and 1.0 cm\(^3\) of pickling reagent solution II and I each) was added. The reagent blank was determined by difference between the first (2 cm\(^3\) of the total reagent volume added) titrated volume of the sodium thiosulfate and the second (4 cm\(^3\) of the total reagent volume added) one. We also carried out experiments for three and four times volume of the reagents. The results are shown in Figure 3.3.1.

The relation between the reagent blank \( V_{\text{bulk, reg}} \) and the volume of the reagents \( V_{\text{reagent}} \) is expressed by equation 2,

\[ V_{\text{bulk, reg}} = -0.0020 V_{\text{reagent}} + 0.0005 \]

There was no difference between the results of DOT-1 and DOT-2. \( V_{\text{bulk, reg}} \) was estimated to be about -0.004 cm\(^3\), suggesting that about 0.02 µmol of reductants was contained in every 2 cm\(^3\) of the reagents added. In other words, the difference of the pure water blank \( V_{\text{bulk, dw}} \) between DOT-1 and DOT-2, determined in the section 3.3.7, was due to the difference of the end-point blank \( V_{\text{bulk, ep}} \) between the two titration apparatus (-0.003 and -0.006 cm\(^3\) for DOT-1 and DOT-2, respectively).

**Sample blank**

Blank due to redox species other than oxygen in the sample \( V_{\text{bulk, spl}} \) can be a potential source of measurement error. Total blank during the seawater measurement, seawater blank \( V_{\text{bulk, sw}} \) can be represented by equation 3,

\[ V_{\text{bulk, sw}} = V_{\text{bulk, spl}} + V_{\text{bulk, ep}} + V_{\text{bulk, reg}} \]

If the end-point blank \( V_{\text{bulk, ep}} \) is identical in pure water and in seawater, the difference between the seawater blank and the pure water one gives the sample blank \( V_{\text{bulk, spl}} \),

\[ V_{\text{bulk, sw}} - V_{\text{bulk, dw}} = V_{\text{bulk, spl}} \]

\( V_{\text{bulk, sw}} \) was determined by following procedure. Seawater sample was collected in the volume calibrated glass flask (ca. 100 cm\(^3\)) without the pickling. Then 1 cm\(^3\) of the standard potassium iodate solution, 1 cm\(^3\) of sulfuric acid solution, and 0.5 cm\(^3\) of pickling reagent solution II and I each were added to the flask in order. Additionally, a flask contained 1 cm\(^3\) of the standard potassium iodate solution, 100 cm\(^3\) of deionized water, 1 cm\(^3\) of sulfuric acid solution, and 0.5 cm\(^3\) of pickling reagent solution II and I were prepared. The difference in the titrant volumes between the seawater flask and the deionized water one gave the sample blank \( V_{\text{bulk, spl}} \).

During this cruise we measured vertical profiles of the sample blanks at two stations (Table 3.3.2) using DOT-1
system. The sample blank ranged from 0.4 to 0.9 \( \mu \text{mol kg}^{-1} \) and its vertical and horizontal variations are small. There are a few reports of the sample blank estimation of oxygen analysis in the open ocean. Our results agree with reported values ranged from 0.4 to 0.8 \( \mu \text{mol kg}^{-1} \) (Culberson et al., 1991). Even if we ignore the sample blank which introduce systematic errors in the oxygen calculations, these errors are expected to be the same for all investigators and not to affect the comparison of results by different investigators (Culberson, 1994).

Table 3.3.2. Results of the sample blank determinations during MR05-02.

<table>
<thead>
<tr>
<th>Sample No. (Niskin No.)</th>
<th>CTD Pres. dbar</th>
<th>Sample blank ( \mu \text{mol kg}^{-1} )</th>
<th>Sample No. (Niskin No.)</th>
<th>CTD Pres. dbar</th>
<th>Sample blank ( \mu \text{mol kg}^{-1} )</th>
</tr>
</thead>
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<tr>
<td>5</td>
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<td>0.5</td>
<td>35</td>
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<tr>
<td>33</td>
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<td>0.6</td>
<td>33</td>
<td>150</td>
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</tr>
<tr>
<td>31</td>
<td>249</td>
<td>0.6</td>
<td>31</td>
<td>251</td>
<td>0.7</td>
</tr>
<tr>
<td>29</td>
<td>402</td>
<td>0.7</td>
<td>29</td>
<td>401</td>
<td>0.9</td>
</tr>
<tr>
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<td>602</td>
<td>0.6</td>
<td>27</td>
<td>601</td>
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<tr>
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<td>0.6</td>
<td>25</td>
<td>801</td>
<td>0.7</td>
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<tr>
<td>23</td>
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<td>0.6</td>
<td>23</td>
<td>1001</td>
<td>0.7</td>
</tr>
<tr>
<td>21</td>
<td>1400</td>
<td>0.7</td>
<td>21</td>
<td>1400</td>
<td>0.7</td>
</tr>
<tr>
<td>17</td>
<td>2200</td>
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<td>15</td>
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<tr>
<td>11</td>
<td>3499</td>
<td>0.6</td>
<td>13</td>
<td>2999</td>
<td>0.7</td>
</tr>
<tr>
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<td>3499</td>
<td>0.7</td>
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<tr>
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<td>4502</td>
<td>0.7</td>
<td>7</td>
<td>3770</td>
<td>0.9</td>
</tr>
</tbody>
</table>

(11) Replicate sample measurement

Replicate samples were taken at every CTD cast. Total amount of the replicate sample pairs in good measurement (flag=2) was 452. The standard deviation of the replicate measurement was 0.11 \( \mu \text{mol kg}^{-1} \) and there was no significant difference between DOT-1 and DOT-2 measurements. The standard deviation was calculated by a procedure (SOP23) in DOE (1994). Figure 3.3.2 is plots of oxygen difference in the replicate measurement as a function of station sequential number and indicates the improvement of measurement skill during the cruise. There found large differences during the primary stage of the cruise. If we exclude the data at the initial ten stations from the calculation of standard deviation, it decreases to 0.09 \( \mu \text{mol kg}^{-1} \).

Figure 3.3.2. Difference in the replicate measurements against station sequential number.
As is shown in Figure 3.3.3, the layers of replicate sampling are localized at the surface layer, 1200, 3000 and 5000 dbar depths. Since scattering of the plots somewhat depend on depths, we classified replicate data in the following categories: surface (<20 dbar), intermediate (500-1500 dbar) and deep (>1500 dbar) layers. Standard deviation for each category is 0.16, 0.11, and 0.07 µmol/kg, respectively.

(12) Duplicate sample measurement

We also collected seawater samples from two Niskin samplers that were fired at same depth (duplicate sampling). Duplicate samples were taken at 49 stations in the deep layer below 2000 dbar, and 48 duplicate sample pairs were obtained successfully. From Figure 3.3.4, variation in measurement resolution is not clear during the period of this cruise. The standard deviation of the total duplicate measurement was about 0.11 µmol/kg. This value is roughly close to the standard deviation of the replicate measurement for the intermediate and deep layers (>500 dbar). Thus, we conclude that our measurement resolution of bottle oxygen is about 0.1 µmol/kg or less for MR05-02 cruise.

(13) CSK standard measurements

The CSK standard solution is a commercial potassium iodate solution (0.0100 N) for analysis of oxygen in seawater. During this cruise, we measured concentration of the CSK standard solution (Lot ASE8280) against our KIO3 standard in order to confirm accuracy of our oxygen measurement on board (Table 3.3.3). Averaged values of DOT-1 and DOT-2 were 0.0099999 ± 0.000002 N and 0.0099999 ± 0.000002 N respectively, which indicates that there was no systematic difference between DOT-1 and DOT-2 measurements. The averaged value of the CSK standard solution was so close to the certified value (0.0100 N) that we did not correct sample measurements with the CSK standard measurements. Additionally, we also measured another batch of the CSK standard solution, Lot TCK8677 that was also measured during our last cruise in 2003 (MR03-K04). We found that the measurements of the two batches of the CSK standard agreed well, suggesting that there was no systematic difference between our oxygen measurements in 2003 and in 2005.
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, 3, 4, 5 and 6 have been assigned (Table 3.3.4). For the choice between 2 (good), 3 (questionable) or 4 (bad), we basically followed a flagging procedure as listed below:

a. On a station-by-station basis, bottle oxygen and difference between bottle oxygen and CTD oxygen at the time of rosette sampling were plotted against CTD pressure. Any points not lying on a generally smooth trend were noted.

b. Dissolved oxygen was then plotted against potential temperature for several stations. If a datum deviated from a group of plots, it was flagged 3 or 4.

c. If the bottle flag was 4 (Did not trip correctly), a datum was noted and flagged 4, respectively. In case of the bottle flag 3 (Leaking), a datum was flagged based on steps a. and b.

Before the publishing of these data, as a post-cruise quality control for bottle oxygen, we carried out one more pass of flagging with the data at all stations. The following step was added.

d. In the oxygen-silicate diagram, data flagged 3 and 4 were examined once more in the mass of all data.

However, we found that all flaggings for 3 and 4 during the cruise were correct, therefore no data was upgraded to flag 2. Lastly, pairs of replicate both flagged 2 were averaged and flagged 6.

References


(14) Quality control flag assignment

<table>
<thead>
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<th>Date (UTC)</th>
<th>KIO3 batch</th>
<th>DOT-1</th>
<th>DOT-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Conc. (N)</td>
<td>error (N)</td>
</tr>
<tr>
<td>2005/6/2</td>
<td>ASE8280-1</td>
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<td>0.000003</td>
</tr>
<tr>
<td>2005/6/11</td>
<td>ASE8280-2</td>
<td>0.010002</td>
<td>0.000003</td>
</tr>
<tr>
<td>2005/6/21</td>
<td>ASE8280-3</td>
<td>0.009999</td>
<td>0.000003</td>
</tr>
<tr>
<td>2005/6/27</td>
<td>ASE8280-4</td>
<td>0.009999</td>
<td>0.000005</td>
</tr>
<tr>
<td></td>
<td>Average</td>
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<td>0.000002</td>
</tr>
<tr>
<td>2005/6/11</td>
<td>TCK8677</td>
<td>0.009999</td>
<td>0.000003</td>
</tr>
</tbody>
</table>

Average 0.009999 0.000002 0.009999 0.000002

Total 3782
3.4 Nutrients

2 July 2005

(1) Personnel

Michio Aoyama (Meteorological Research Institute / Japan Meteorological Agency, Principal Investigator)
Junko Hamanaka (Marine Works Japan Ltd.)
Asako Kubo (Marine Works Japan Ltd.)
Ayumi Takeuchi (Marine Works Japan Ltd.)

(2) Objectives

The objectives of nutrients analyses during the R/V Mirai MR0502 cruise along 149 °E line in the Western North Pacific are as follows;

Describe the present status of nutrients in good traceability.
The target nutrients are nitrate, nitrite, phosphate and silicate (Although silicic acid is correct, we use silicate because a term of silicate is widely used in oceanographic community).
Study temporal and spatial variations of nutrients based on the previous high quality experiments data of WOCE, GOSECS, IGY and so on.
Study temporal and spatial variation of nitrate: phosphate ratio, so-called Redfield ratio.
Obtain more accurate estimation of total amount of nitrate, phosphate and silicate in the interested area.
Provide more accurate nutrients data for physical oceanographers to use as tracers for water mass movement.

(3) Equipment and techniques

a. Analytical detail using TRAACS 800 systems (BRAN+LUEBBE)

The phosphate analysis is a modification of the procedure of Murphy and Riley (1962).
Molybdic acid is added to seawater sample to form phosphomolybdic acid which is in turn reduced to phosphomolybdous acid using L-ascorbic acid as reductant.
Nitrate + nitrite and nitrite are analyzed according to the modification method of Grasshoff (1970).
The sample nitrate is reduced to nitrite in a cadmium tube inside of which is coated with metallic copper. The sample stream with its equivalent nitrite is treated with an acidic, sulfanilamide reagent and the nitrite forms nitrous acid which reacts with the sulfanilamide to produce a diazonium ion. N1-Naphthylethylene-diamine added to the sample stream then couples with the diazonium ion to produce a red, azo dye. With reduction of the nitrate to nitrite, both nitrate and nitrite react and are measured; without reduction, only nitrite reacts. Thus, for the nitrite analysis, no reduction is performed and the alkaline buffer is not necessary. Nitrate is computed by difference.
The silicate method is analogous to that described for phosphate. The method used is essentially the same as that of Grasshoff et al. (1983), where silicomolybdic acid is first formed from the silic acid in the sample and added molybdic acid; then the silicomolybdic acid is reduced to silicomolybdous acid, or "molybdenum blue," using ascorbic acid as the reductant.
The flow diagrams and regents for each parameter are shown in Figures 3.4.1-3.4.4.
Nitrate Reagents
Imidazole (buffer), 0.06 M (0.4 % w/v)
Dissolve 4 g imidazole, C₃H₄N₂, in ca. 900 ml DIW; add 2 ml concentrated HCl; make up to 1000 ml with DIW. After mixing, 1 ml Triton® X-100 (50 % solution in ethanol) is added.

Sulfanilamide, 0.06 M (1 % w/v) in 1.2 M HCl
Dissolve 10 g sulfanilamide, 4-NH₂C₆H₄SO₃H, in 1000 ml of 1.2 M (10 %) HCl. After mixing, 1 ml Triton® X-100 (50 % solution in ethanol) is added.

N-1-Naphthylethylene-diamine dihydrochloride, 0.004 M (0.1 % w/v)
Dissolve 1 g NEDA, C₁₀H₇NHCH₂CH₂NH₂·2HCl, in 1000 ml of DIW; containing 10 ml concentrated HCl. Stored in a dark bottle.

Nitrite Reagents
Sulfanilamide, 0.06 M (1 % w/v) in 1.2 M HCl
Dissolve 10 g sulfanilamide, 4-NH₂C₆H₄SO₃H, in 1000 ml of 1.2 M (10 %) HCl. After mixing, 1 ml Triton® X-100 (50 % solution in ethanol) is added.

N-1-Naphthylethylene-diamine dihydrochloride, 0.004 M (0.1 % w/v)
Dissolve 1 g NEDA, C₆H₄N₂H₆CH₃NH₂·2HCl, in 1000 ml of DIW; containing 10 ml concentrated HCl. Stored in a dark bottle.
**Silicic Acid Reagents**

Molybdate, 0.06 M (2 % w/v)

Dissolve 15 g Disodium Molybate(VI) Dihydrate, Na₂MoO₄·2H₂O, in 1000 ml DIW containing 6 ml H₂SO₄. After mixing, 20 ml sodium dodecyl sulphate (15 % solution in water) is added.

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

Dissolve 50 g Oxalic Acid Anhydrous, HOOC·COOH, in 1000 ml of DIW.

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

Dissolve 2.5 g L (+)-Ascorbic Acid, C₆H₈O₆, in 100 ml of DIW. Stored in a dark bottle and freshly prepared before every measurement.

**Phosphate Reagents**

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

Dissolve 8 g Disodium Molybate (VI) Dihydrate, Na₂MoO₄·2H₂O, and 0.17 g Antimony Potassium Tartrate, C₈H₄K₂O₁₂Sb₂·3H₂O, in 1000 ml of DIW containing 50 ml concentrated H₂SO₄.

Mixed Reagent

Dissolve 0.8 g L (+)-Ascorbic Acid, C₆H₇O₆, in 100 ml of stock molybdate solution. After mixing, 2 ml sodium dodecyl sulphate (15 % solution in water) is added. Stored in a dark bottle and freshly prepared before every measurement.

PO₄ dilution

Dissolve Sodium Hydrate, NaCl, 10 g in ca. 900 ml, add 50 ml Acetone and 4 ml concentrated H₂SO₄, make up to 1000 ml. After mixing, 5 ml sodium dodecyl sulphate (15 % solution in water) is added.
b. Sampling procedures

Sampling of nutrients followed that of oxygen, trace gases and salinity. 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 are put into water a bath at 26 °C for 10 minutes before using to stabilize the temperature of samples.

No transfer was made and the vials were set in an auto sampler tray directly. Samples were analyzed after collection, basically within 17 hours.

c. Data processing

Raw data from TRAACS800 were treated as follows;

Check baseline shift.

Check the shape of each peak and positions of peak values taken, and then change the positions of peak values taken, if necessary.

Carryover 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.

Load pressure and salinity from CTD data to calculate density of seawater.

Calibration curves to get nutrients concentration were assumed second order equations.

(4) Nutrients standards

a. In-house standards

(i) Volumetric Laboratory Ware

All volumetric glass- and plastic (PMP)-ware used were gravimetrically calibrated. Plastic volumetric flasks were gravimetrically calibrated at the temperature of use within 2-3 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, which is 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 silicic acid from the glass. High quality plastic (polymethylpentene, PMP, or polypropylene) volumetric flasks were gravimetrically calibrated and used only within 3-4 K of the calibration temperature.

The computation of volume contained by glass flasks at various temperatures other than the calibration temperatures was 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 3-4 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.

(ii) Reagents, General considerations

General Specifications

All reagents were of very high purity such as “Analytical Grade,” “Analyzed Reagent Grade” and others. And assay of nitrite was determined according to JISK8019 and assays of nitrite salts were 98.9 %. We use that value to adjust the weights taken.

For the silicate standards solution, we use commercial available silicon standard solution for atomic absorption spectrometry of 1000 mg l⁻¹. Since this solution is alkaline solution of 0.5 M KOH, an aliquot of 40 ml solution was diluted to 500 ml as B standard together with an aliquot of 20 ml of 1M HCl. Then the pH of B standard for silicate prepared to be 6.9.
Ultra pure water

Ultra pure water (MilliQ water) was used for preparation of reagents, higher concentration standards and for measurement of reagent and system blanks.

Low-Nutrient Seawater (LNSW)

Surface water with 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 carefully measured in March 2005.

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

Concentrations of nutrients for A, B and C standards are set as shown in Table 3.4.1. The C standard is prepared according to the recipes as shown in Table 3.4.2. 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 laboratory wares.

Table 3.4.1. Nominal concentrations of nutrients for A, B and C standards.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C-1</th>
<th>C-2</th>
<th>C-3</th>
<th>C-4</th>
<th>C-5</th>
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<tbody>
<tr>
<td>NO₃ (µM)</td>
<td>45000</td>
<td>900</td>
<td>0</td>
<td>9</td>
<td>27</td>
<td>45</td>
<td>54</td>
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<tr>
<td>NO₂ (µM)</td>
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<td>0</td>
<td>0.2</td>
<td>0.6</td>
<td>1.0</td>
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<tr>
<td>SiO₂ (µM)</td>
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<tr>
<td>PO₄ (µM)</td>
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<td>60</td>
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<td>0.6</td>
<td>1.8</td>
<td>3.0</td>
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</table>

(iv) Renewal of in-house standard solutions

In-house standard solutions as stated in (iii) were renewed as shown in Table 3.4.3.

Table 3.4.2. Working calibration standard recipes.

<table>
<thead>
<tr>
<th></th>
<th>C-STD</th>
<th>B-1 STD</th>
<th>B-2 STD</th>
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<td>0 ml</td>
<td>0 ml</td>
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</tr>
<tr>
<td>C-2</td>
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</tr>
<tr>
<td>C-3</td>
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</tr>
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<td>C-4</td>
<td>25 ml</td>
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<td>10 ml</td>
<td></td>
</tr>
<tr>
<td>C-5</td>
<td>30 ml</td>
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<td>0 ml</td>
<td></td>
</tr>
</tbody>
</table>

B-1 STD: Mixture of nitrate, silicate and phosphate
B-2 STD: Nitrite

Table 3.4.3. Timing of renewal of in-house standards.

<table>
<thead>
<tr>
<th>NO₃, NO₂, SiO₂, PO₄</th>
<th>Renewal</th>
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<tr>
<td>A-1 Std. (NO₃)</td>
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</tr>
<tr>
<td>A-2 Std. (NO₂)</td>
<td>maximum 1 month</td>
</tr>
<tr>
<td>A-3 Std. (SiO₂)</td>
<td>commercial prepared solution</td>
</tr>
<tr>
<td>A-4 Std. (PO₄)</td>
<td>maximum 1 month</td>
</tr>
<tr>
<td>B-1 Std. (mixture of NO₃, SiO₂, PO₄)</td>
<td>3 days</td>
</tr>
<tr>
<td>B-2 Std. (NO₂)</td>
<td>6 days</td>
</tr>
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b. RMNS

To get more accurate and high quality nutrients data for achieving the objectives stated above, huge numbers of the bottles of the reference material of nutrients in seawater (hereafter RMNS) are prepared (Aoyama et al., submitted). In the previous world wide expeditions, such as WOCE cruises, 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 %, 1-2 %, 1-3 % for nitrate, phosphate and silicate, respectively. Although nutrient data from the WOCE one-time survey had unprecedented quality and coverage due to the utmost care in sampling and measurements, the differences of nutrients concentration at crossover points are still found among the expeditions (Aoyama and Joyce, 1996, Mordy et al., 2000, Gouretski and Jancke, 2001). For instance, the mean offset of nitrate concentration at deep waters was 0.5 µmol kg\(^{-1}\) for 345 crossovers at the world oceans, though the maximum was 1.7 µmol kg\(^{-1}\) (Gouretski and Jancke, 2001). At the 31 crossover points in the Pacific WHP one-time lines, the WOCE standard of reproducibility for nitrate of 1 % was fulfilled at about half of the crossover points and the maximum difference was 7 % at deeper layers below 1.6 °C in potential temperature (Aoyama and Joyce, 1996).

(i) RMNS preparation

**RMNS preparation and homogeneity for previous lots**

The study on reference material for nutrients in seawater (RMNS) on the seawater base has been carried out to establish traceability on nutrient analyses in seawater since 1994, in Japan. Autoclaving to produce RMNS has been studied (Aminot and Kerouel, 1991, 1995) and autoclaving was used to stabilize the samples for the 5th intercomparison exercise in 1992/1993 (Aminot and Kirkwood, 1995). Aminot and Kerouel (1995) concluded that nitrate and nitrite were extremely stable throughout their 27 months storage experiment with overall standard deviations lower than 0.3 % (range 5-50 µmol l\(^{-1}\)) and 0.8 % (range 0.5-5 µmol l\(^{-1}\)), respectively. For phosphate, slight increase by 0.02-0.07 µmol l\(^{-1}\) per year was observed due to leaching from the container glass. The main source of nutrient variation in seawater is believed to be microorganism activity, hence, production of RMNS depends on biological inactivation of samples. In this point of view, previous study showed that autoclaving to inactivate the biological activity is acceptable for RMNS preparation.

In the R/V Mirai BEAGLE2003 cruise, which was round-the-world cruise along ca. 30 °S and conducted in 2003 and 2004, RMNS was analyzed at about 500 stations during the cruises. The results of BEAGLE2003 cruise will be available soon. (Databook of BEAGLE2003, 2005)

The seawater for RMNS production was sampled in the North Pacific Ocean at the depths of the surface where the nutrients are almost depleted and at 1500-2000 meters depth where the nutrients concentrations are the maximum. The seawater was gravity-filtered through a membrane filter with a pore size of 0.45 µm (Millipore HA). The latest procedure of autoclaving for RMNS preparation is that the seawater in a stainless steel container of 40 liters was autoclaved at 120 °C, for 2 hours, 2 times in two days. The filling procedure of autoclaved seawater was basically same throughout our study. Following cooling at room temperature in two days, polypropylene bottle of 100 ml capacity were filled by the autoclaved seawater of 90 ml through a membrane filter with a pore size of 0.2 µm (Millipore HA) at a clean bench in a clean room. The polypropylene caps were immediately and tightly screwed on and a label containing lot number and serial number of the bottle was attached on all the bottles. Then the bottles were vacuum-sealed to avoid potential contamination from the environment.
**RMNs for this cruise**

RMNs lots BC, AV, AX, AY and BA, which covers full range of nutrients concentrations in the western North Pacific are prepared as packages. These packages were renewed daily and analyzed every 2-6 runs on the same day. 150 bottles of RMNs lot AZ are prepared to use every analysis at every hydrographic station. These RMNs assignment were completely done based on random number. The RMNs bottles were stored at a room, REGENT STORE, where the temperature was maintained at around 26-28 °C.

(ii) The homogeneity of RMNs and consensus values of the lot AH

The homogeneity of lot BC and analytical precisions are shown in Table 3.4.4. These are for the assessment of the magnitude of homogeneity of the RMNs bottles that are used during the cruise. As shown in Table 3.4.4, the homogeneity of RMNs lot BC for nitrate and silicate are the same magnitude

<table>
<thead>
<tr>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV %</td>
<td>CV %</td>
<td>CV %</td>
</tr>
<tr>
<td>BC</td>
<td>0.22 %</td>
<td>0.32 %</td>
</tr>
<tr>
<td>(AH)</td>
<td>(0.39 %)</td>
<td>(0.83 %)</td>
</tr>
<tr>
<td>(K)</td>
<td>(0.3 %)</td>
<td>(1.0 %)</td>
</tr>
<tr>
<td>Precision</td>
<td>0.22 %</td>
<td>0.22 %</td>
</tr>
</tbody>
</table>

Table 3.4.4. Homogeneity of lot BC and previous lots derived from simultaneous 30 samples measurements and analytical precision onboard R/V Mirai in May 2005.

(5) Quality control

a. Precision of nutrients analyses during the cruise

Precision of nutrients analyses during the cruise was evaluated based on the 12 measurements, which were measured every 12 samples, during a run at the concentration of C-5. We also evaluated the reproducibility based on the replicate analyses of five samples in each run. Summary of precisions are shown in Table 3.4.5. As shown in Table 3.4.5 and Figures 3.4.5-3.4.7, the precisions for each parameter are generally good, considering the analytical precisions estimated from the simultaneous analyses of 60 samples in May 2005. Analytical precisions previously evaluated were 0.22 % for phosphate, 0.22 % for nitrate and 0.12 % for silicate, respectively. During this cruise, analytical precisions were 0.12 % for phosphate, 0.09 % for nitrate and 0.08 % for silicate in terms of median of precision, respectively. Then we can conclude that the analytical precisions for phosphate, nitrate and silicate were maintained or better throughout this cruise, comparing the pre-cruise evaluations. The time series of precision are shown in Figures 3.4.5-3.4.7.

<table>
<thead>
<tr>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV %</td>
<td>CV %</td>
<td>CV %</td>
</tr>
<tr>
<td>Median</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>Mean</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.17</td>
<td>0.29</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.03</td>
<td>0.05</td>
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<tr>
<td>N</td>
<td>126</td>
<td>126</td>
</tr>
</tbody>
</table>

Table 3.4.5. Summary of precision based on the replicate analyses of 12 samples in each run through out cruise.
b. Carry over

We can also summarize the magnitudes of carryover throughout the cruise. These are as shown in Table 3.4.6.

<table>
<thead>
<tr>
<th></th>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Silicate</th>
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</thead>
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<tr>
<td>Median</td>
<td>0.30</td>
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<td>0.21</td>
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<tr>
<td>Mean</td>
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<tr>
<td>Maximum</td>
<td>0.50</td>
<td>0.71</td>
<td>0.38</td>
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<tr>
<td>Minimum</td>
<td>0.10</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>N</td>
<td>126</td>
<td>126</td>
<td>126</td>
</tr>
</tbody>
</table>
(6) Evaluation of trueness of nutrients concentrations using RMNSs

We have been using RMNS for all runs, then, we can evaluate the trueness of nutrients concentration throughout the cruise. Results of RMNS measurements are shown in Figures 3.4.8-3.4.10.

The uncertainties of nitrate, phosphate and silicate measurements for this cruise were evaluated as functions of concentrations of those. Uncertainties of nitrate measurement are expressed by eq. (1).

\[
\text{Uncertainties} \% = 0.13 + 1.66 / \text{C}_{\text{nitrate}}
\]

Where \( \text{C}_{\text{nitrate}} \) is nitrate concentration in \( \mu\text{mol kg}^{-1} \).

Uncertainties of phosphate measurement are expressed eq. (2).

\[
\text{Uncertainties} \% = -0.11 + 1.032 / \text{C}_{\text{phos}}
\]

Where \( \text{C}_{\text{phos}} \) is phosphate concentration in \( \mu\text{mol kg}^{-1} \).

Uncertainties of silicate measurement are expressed eq. (3).

\[
\text{Uncertainties} \% = 0.095 + 4.92 / \text{C}_{\text{silicate}}
\]

Where \( \text{C}_{\text{silicate}} \) is silicate concentration in \( \mu\text{mol kg}^{-1} \).

Then, three columns to show the uncertainties of nutrients measurement were created in the sea file of this cruise.

Figure 3.4.8. Time series of nitrate concentration for RMNSs.
Figure 3.4.9. Same as Figure 3.4.8, but for phosphate.

Figure 3.4.10. Same as Figure 3.4.8, but for silicic acid.
Cruise-to-cruise traceability was examined based on the previous results of RMNSs obtained from several cruises and laboratory analyses. As shown in table 3.4.7, the nutrients concentration of RMNSs was in good agreement among experiments.

Problems/improvements occurred and solutions

As shown in Figure 3.4.7, the precisions of silicate concentration reached 0.15-0.19 % at several stations before station 118, where serial number of the station is 26. The cause of relatively higher precisions was attributed to be larger ambient temperature variability up to 1 °C around 30 minutes interval. We re-arranged a setting of room temperature control to be more stable and obtained less room temperature variability around 0.5 °C. Then we can see much better precision of silicate analyses after re-arrangement as shown in Figure 3.4.7.

References


<table>
<thead>
<tr>
<th>Cruise/Lab</th>
<th>RM Lots</th>
<th>AX</th>
<th>AV</th>
<th>BC</th>
<th>AZ</th>
<th>AH</th>
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<td></td>
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<td></td>
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</tr>
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<td>2.99</td>
<td>2.08</td>
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<tr>
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<td>2.78</td>
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<tr>
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<td>59.4</td>
<td>157.7</td>
<td>135.5</td>
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<td></td>
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<td>159.5</td>
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<td>MR0502</td>
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<td>157.9</td>
<td>159.9</td>
<td>137.1</td>
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</tr>
</tbody>
</table>

(7) Cruise-to-cruise traceability

Cruise-to-cruise traceability was examined based on the previous results of RMNSs obtained from several cruises and laboratory analyses. As shown in table 3.4.7, the nutrients concentration of RMNSs was in good agreement among experiments.


Gouretski, V.V. and Jancke, K. 2001. Systematic errors as the cause for an apparent deep water property variability: global analysis of the WOCE and historical hydrographic data • REVIEW ARTICLE, Progress In Oceanography, 48: Issue 4, 337-402.
3.5 Dissolved Inorganic Carbon (Cₐ)

31 August, 2006

(1) Personnel
Akihiko Murata (IORGC/JAMSTEC)
Mikio Kitada (MWJ)
Yoshiko Ishikawa (MWJ)

(2) Introduction
Concentrations of CO₂ in the atmosphere are now increasing at a rate of 1.5 ppmv year⁻¹ due to human activities such as burning of fossil fuels, deforestation, cement production, and so on. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO₂, as well as to clarify the mechanism of CO₂ absorption, because the magnitude of predicted global warming depends on the levels of CO₂ in the atmosphere, and the ocean currently absorbs 1/3 of the 6 Gt of carbon emitted into the atmosphere each year by human activities.

In this cruise (revisit of WOCE P10 line), we aimed to quantify how much anthropogenic CO₂ is absorbed in North Pacific Intermediate Water, which is one of characteristic waters in the North Pacific. For the purpose, we measured CO₂-system properties such as dissolved inorganic carbon (Cₐ), total alkalinity (Aₑ), pH and underway pCO₂.

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

(2) Apparatus
Measurements of Cₐ were made with two total CO₂ measuring systems (systems A and B; 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 5012, UIC Inc.).

The seawater dispensing system has an auto-sampler (6 ports), which takes seawater from a 300 ml borosilicate glass bottle and dispenses the seawater to a pipette of nominal 20 or 28 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. To degas CO₂ as quickly as possible, a heating wire kept at 40 °C was rolled from the bottom to a 1/3 height of the stripping chamber. 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 (flow rates of 130 ml min⁻¹ and 140 ml min⁻¹ for the systems A and B, respectively) to the coulometer through a dehydrating module. For the system A, the module consists of two electric dehumidifiers (kept at 1 - 2 °C) and a chemical desiccant (Mg(ClO₄)₂). For the system B, it consists of three electric dehumidifiers with a chemical desiccant.

(3) Shipboard measurement
Sampling
All seawater samples were collected from depth with 12 liter Niskin bottles basically at every other station. The seawater samples for Cₐ 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 smoothly filled with seawater from the bottom following a rinse with seawater of 2 full bottle volumes. The glass bottle was closed by a stopper, which was gravimetrically fitted to the bottle mouth without putting additional force.

At a chemical laboratory on the ship, a headspace of approx. 1 % of the bottle volume 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 4 °C in a refrigerator until analysis. A few hours just before analysis, the seawater samples were kept at 20 °C in a water bath.

**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), 2 % CO2 gas in a nitrogen base, seawater samples (6) was programmed to repeat. The measurement of 2 % CO2 gas was made to monitor response of coulometer solutions (from UIC, Inc.). For every renewal of coulometer solutions, certified reference materials (CRM, batch 69) provided by Prof. A. G. Dickson of Scripps Institution of Oceanography were analyzed. In addition, reference materials (RM) provided by JAMSTEC (2 kinds) and KANSO 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\textsubscript{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\textsubscript{T} on board the ship. As we used two systems, we had not encountered such a situation that we had to abandon the measurement due to time limitation. However, we experienced some malfunctions of the measuring systems during the cruise, which are described in the followings:

There occurred lowering of repeatability, mostly due to dirt. This situation was recovered by cleaning the measuring systems. For the system B, we could not recover good repeatability (\( \pm 1.5 \) µmol kg\(^{-1} \)). To obtain good repeatability, we changed the pipette of a volume of 20 ml to that of a volume of 28 ml;

The “undershooting” of coulometer detection was often found. This happened in measuring seawater samples subsequent to the measurement of phosphoric acid blank. To avoid the “undershooting” occurred in seawater sample measurement, we measured a dummy seawater sample subsequent to the bank measurement.

**Quality control**

Calibration factors of the systems A and B were listed in Table 3.5.1. With these factors, we calculated C\textsubscript{T} of CRM (batch 69), and plotted the values as a function of sequential day (Fig. 3.5.1). From Fig. 3.5.1, it is found that there were no trends of CRM measurements for both the systems. The averages and standard deviations were 1906.7 and 0.7 µmol kg\(^{-1} \) (n = 36), respectively, for the system A and 1907.2 and 1.1 µmol kg\(^{-1} \) (n = 28), respectively for the system B. Since the certified value of the batch 69 is 1907.63 µmol kg\(^{-1} \), very close to the averages, it implies that the measurements had been conducted in a good condition during the cruise.

Based on the results of CRM measurements stated above, we re-calculated the calibration factors so that measurements of seawater samples become traceable to the certified value of batch 69.

Temporal variations of RM measurements are shown in Fig. 3.5.2. From Fig. 3.5.2, it is evident that RM measurements had a linear trend, implying that measurements of seawater samples also have the trend. The trend was also found in temporal changes of 2 % 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 to be traceable to the certified value of batch 69, although the adjustments were usually slight.

Finally we surveyed vertical profiles of C\textsubscript{T}. In particular, we examined whether systematic differences between measurements of the systems A and B existed or not. Then taking other information of analyses into account, we determined a flag of each value of C\textsubscript{T}.

The average and standard deviation of absolute values of differences of C\textsubscript{T} analyzed consecutively were 1.2 and 1.1 µmol kg\(^{-1} \) (n = 209), respectively.

**Reference**

Table 3.5.1. Calibration factors determined from Na₂CO₃ solutions.

<table>
<thead>
<tr>
<th>Cruise Name</th>
<th>Calibration factors</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>MR05-02</td>
<td>0.24479</td>
<td>A pipette for the system B was replaced</td>
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<tr>
<td></td>
<td>0.31326</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.5.1. Temporal variations of CRM (Batch 69) $C_T$ measured by the systems A and B.

Figure 3.5.2. An example of temporal variations of RM $C_T$. The line was determined by the least squared method. $C_T$ increased at a rate of approx. 2.9 μmol kg⁻¹ per day.
3.6 Total Alkalinity ($A_t$)  

10 October, 2006

(1) Personnel
Akihiko Murata (IORGC/ JAMSTEC)  
Fuyuki Shibata (MWJ)  
Taeko Ohama (MWJ)

(2) Introduction
Concentrations of CO$_2$ in the atmosphere are now increasing at a rate of 1.5 ppmv yr$^{-1}$ due to human activities such as burning of fossil fuels, deforestation, cement production, and so on. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO$_2$, as well as to clarify the mechanism of the CO$_2$ absorption, because the magnitude of predicted global warming depends on the levels of CO$_2$ in the atmosphere, and the ocean currently absorbs 1/3 of the 6 Gt of carbon emitted into the atmosphere each year by human activities.

In this cruise (revisit of WOCE P10 line), we aimed to quantify how much anthropogenic CO$_2$ is absorbed in North Pacific Intermediate Water, which is one of the characteristic waters in the North Pacific. For the purpose, we measured CO$_2$-system properties such as dissolved inorganic carbon (CT), total alkalinity ($A_t$), pH and underway pCO$_2$.

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

(2) Apparatus
The measuring system for $A_t$ (customized by Nippon ANS, Inc.) comprises of a water dispensing unit, an auto-burette (Metrohm), a pH meter (Thermo Orion) and auto-sampler (6 ports). They are automatically controlled by a PC. Separate electrodes (Reference electrode: REF201, Radiometer), Glass pH electrode: pHG201-7 (Radiometer), or combined electrodes (ROSS 8102BN, Thermo Orion) were used.

A seawater of approx. 40 ml is transferred from a sample bottle (borosilicate glass bottle; 130 ml) into a water-jacketed (25 °C) by pressurized N$_2$ gas, and is introduced into a water-jacketed (25 °C) titration cell. Next, a given volume of titrant is injected into the titration cell. By this, pH of a seawater sample becomes 4.5 - 4.0. The seawater sample mixed with the titrant is stirred for three minutes by a stirring chip. Then a small volume of titrant (~0.1 ml) is injected until pH or e.m.f. reaches a given value. The concentration of the acid titrant is nominally 0.05 M HCl in 0.65 M NaCl.

Calculation of $A_t$ is made based on a modified Gran approach.

(3) Shipboard measurement

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 seawater of a half a or a full bottle volume. A few hours before analysis, the seawater samples were kept at 25 °C in a water bath.

Analysis
For $A_t$ measurement, we selected electrodes, which showed signals close to theoretical Nernstian behavior.

At the start of each leg, we conducted calibration of the acid titrant, which was prepared on land. The calibration was made by measuring $A_t$ of 5 solutions of Na$_2$CO$_3$ in 0.7 M NaCl solutions. The computed $A_t$s were approx. 0, 100, 1000, 2000 and 2500 µmol kg$^{-1}$. The measured values of $A_t$ (calculated by assuming 0.05 M acid titrant) should be a linear function of the $A_t$ contributed by the Na$_2$CO$_3$. The linear function was fitted by the method of least squares. Theoretically, the slope of the linear function should be unity. If the measured slope is not equal to unity, the acid normality should be adjusted by dividing initial normality by the slope, and the whole set of calculations is repeated until the slope = 1.

Before starting analyses of seawater samples, we measured $A_t$ of dummy seawater samples to confirm a
condition of the measuring system. If repeat measurements of $A_t$ were constant within $\sim 3 \mu\text{mol kg}^{-1}$, we initiated measurement of seawater samples. We analyzed reference materials (RM), which were produced for $C_O$ measurement by JAMSTEC, but were efficient also for the monitor of $A_t$ measurement. In addition, certified reference materials (CRM, batch 69, certified value $= 2114.42 \mu\text{mol kg}^{-1}$) 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.

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 such serious problems that we had to give up the analyses. However, we experienced some malfunctions of the system during the cruise, which are listed in the followings:

After analyses of a large number of samples, we often experienced a drift of an electrode, which appeared as differences of pH or e.m.f. against a constant volume of titrant injected into a seawater sample. In this case, we changed pH or e.m.f. ranges for the subsequent calculation of $A_t$.

(4) Quality control

We examined vertical profiles of $A_t$. Then, taking other information of analyses into account, we determined a flag of each value of $A_t$.

The average and standard deviation of absolute values of differences of $A_t$ analyzed consecutively were $1.8$ and $1.6 \mu\text{mol kg}^{-1}$ ($n = 207$), respectively.
3.7 pH

12 October, 2006

(1) Personnel
Akihiko Murata (IORGC, JAMSTEC)
Fuyuki Shibata (MWJ)
Taeko Ohama (MWJ)

(2) Introduction
Concentrations of CO2 in the atmosphere are now increasing at a rate of 1.5 ppmv y^{-1} due to human activities such as burning of fossil fuels, deforestation, cement production, and so on. It is an urgent task to estimate as accurately as possible the absorption capacity of the oceans against the increased atmospheric CO2, as well as to clarify the mechanism of the CO2 absorption, because the magnitude of anticipated global warming depends on the levels of CO2 in the atmosphere, and the ocean currently absorbs 1 / 3 of the 6 Gt of carbon emitted into the atmosphere each year by human activities.

In this cruise (revisit of WOCE P10 line), we aimed to quantify how much anthropogenic CO2 absorbed in North Pacific Intermediate Water, which is one of the characteristic waters in the North Pacific. For the purpose, we measured CO2-system properties such as dissolved inorganic carbon (CT), total alkalinity (AT), 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 the 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 absorbance of seawater + indicator are measured at the same wavelengths.

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

\[
pH = pK_2 + \log \left( \frac{A_1}{A_2} - \frac{0.00691}{2.2220 - 0.1331(A_1/A_2)} \right) \tag{1}
\]

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

(3) Shipboard measurement

Sampling
All seawater samples were collected from depth with 12 liter Niskin bottles basically at every other station. 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, which was the same as used for CT sampling. 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 with a stopper, which was gravimetrically fitted to the bottle mouth without additional force. A few hours before analysis, the seawater samples were kept at 25 °C in a water bath.

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 initially in the range 1.4 - 1.6, and decreased to 1.1.
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 alone and seawater + indicator solutions were measured 15 times each, and averages computed from the last five values of absorbance were 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 such a serious problem that we had to give up the analyses. However, we sometimes experienced malfunctions of the system during the cruise:

Differences between absorbances of seawater alone and those of seawater + indicator solution were infrequently greater than ± 0.001. This implies dirt of the cell. In this case, we cleaned or replaced the cell.

(4) Quality control

It is recommended that correction for pH change resulting from addition of indicator solutions is made (DOE, 1994). To check 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). Figure 3.7.1 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 average and standard deviation of absolute values of differences of pH analyzed consecutively were 0.0006 and 0.0006 pH unit (n = 203), respectively.

References


Figure 3.7.1. Perturbation of absorbance ratios by adding indicator solutions. The line ($y = -0.0848x + 0.1633$, $R^2 = 0.7703$) was determined by the method of least squares.
3.8 Chlorofluorocarbons (CFCs)

2 October 2006

(1) Personnel

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Masahide WAKITA (MIO, JAMSTEC)
Hideki YAMAMOTO (MWJ)
Katsunori SAGISHIMA (MWJ)
Yuichi SONOYAMA (MWJ)

(2) Introduction

Chlorofluorocarbons (CFCs) are completely man-made gasses that are chemically and biologically stable gasses in the environment. The CFCs have accumulated in the atmosphere since 1930s (Walker et al., 2000) and the atmospheric CFCs can slightly dissolve in sea surface water. The dissolved CFCs concentrations in sea surface water should have changed year by year and then penetrate into the ocean interior by water circulation. Three chemical species of CFCs, namely CFC-11 (CCl₃F), CFC-12 (CCl₂F₂) and CFC-113 (C₂Cl₃F₃), dissolved in seawater are useful transient tracers for the ocean circulation with times scale on the order of decades.

In this cruise, we determined concentrations of these CFCs in seawater on board.

(3) Apparatus

Dissolved CFCs were measured by a typical method modified from the original design of Bullister and Weiss (1988). Two systems were used for CFCs measurement. A custom made purging and trapping system was attached to gas chromatograph (GC-14B: Shimadzu Ltd) having an electron capture detector (ECD-14: Shimadzu Ltd). Stainless steel tube packed Porapak T® was used as a cold trap. Silica Plot capillary column [i.d.: 0.53 mm, length: 4 m, tick: 0.25 µm] and a complex capillary column (Pola Bond-Q [i.d.: 0.53 mm, length: 7 m, tick: 6.0 µm] followed by Silica Plot [i.d.: 0.53 mm, length: 22 m, tick: 0.25 µm]) was used as a pre-column and main column, respectively.

(4) Shipboard measurement

Sampling

Before casting CTD, the water sampling system was cleaned by diluted acetone to remove any oils which could cause contaminations of CFCs. Seawater sub-samples for CFCs measurement were collected from 12 liter Niskin bottles into 300ml glass bottle. The bottle had been filled with pure nitrogen gas before the sub-sampling. The two times bottle volumes of seawater sample were overflowed. The bottles filled with seawater were kept in water bathes roughly controlled on the sample temperature. The CFCs concentrations were determined as soon as possible.

Analysis

Constant volume of sample water (50ml) was taken into the purging & trapping system. Dissolved CFCs were de-gassed by nitrogen gas purge and concentrated in a trap column cooled to −40 °C. The CFCs were desorbed by electrically heating the trap column to 140 °C within 1.5 minutes, and led into the pre-column. CFCs and other compounds were roughly separated in the pre-column and the compounds having earlier retention time than CFCs were sent to main analytical column. And then the pre-column was flushed back by counter flow of pure nitrogen gas (Back flush system). The back flush system prevented any compounds that had higher retention time than CFCs from entering main analytical column and allowed short time analysis. CFCs which were sent into main column were separated further and detected by an electron capture detector (ECD). Retention time of each CFC was around 1.5, 4.2 and 10.5 minutes for CFC-12, CFC-11 and CFC-113, respectively. Temperatures of an analytical column and a detector were 95 and 240 °C, respectively. Pure nitrogen gas (99.999%) was purified by a molecular sieve 13X gas purifier and was used for CFCs analysis. Mass flow rates of nitrogen gas were 21, 16, 20 and 200 ml/min for carrier, detector make up, back flush and sample purging gasses, respectively.

Gas loops whose volumes were around 1, 3 and 10 ml were used for introducing standard gases into the analytical system. The standard gases had been made by Japan Fine Products co. ltd. Cylinder numbers of CPB30524 and CPB30525 of standard gases were used for reference gas and running gas, respectively. These gases contained roughly 300, 160 and 30 ppt (v/v) of CFC-11, CFC-12 and CFC-113, respectively (nitrogen base). Precise mixing ratios of the standard gases were calculated by gravimetric data. The standard gases used in this cruise have
not been calibrated to SIO scale standard gases yet because SIO scale standard gases is hard to obtain due to legal
difficulties for CFCs import into Japan. The data will be corrected as soon as possible when we obtain the standard
gases.

(4) Quality control

Blank

Some blank water samples which were made by nitrogen purge of seawater in CFCs sample bottle were analyzed
and any CFCs were not detected. Significant increase in CFCs concentration during keeping sampling bottle in a
water bath was not found for around one week. CFCs concentrations in deep water which was one of the oldest water
masses in the ocean were low but not zero for CFC-11 and -12. Average concentrations of CFC-11, 12 in denser
water than 27.5 sigma-0 were 0.022 ± 0.011, 0.004 ± 0.004 (n = 449). These values were assumed as sampling blanks
which was contaminations from Niskin bottle and/or during sub-sampling and were subtracted from all data.

Interfering compound for CFC-113 analysis

A large and broad peak was interfered determining CFC-113 peak area for samples collected from surface 200 m
depth in the latitude band between 33 °N and 8 °N. Retention time of the interfering peak was around 3 % shorter
than that of CFC-113. The peak of a compound interfering CFC-113 determination could not be completely separated
from the peak of CFC-113 by our analytical condition. We tried to split these peaks on chromatogram analysis and
give flag “4”. In the case of the interfering peak completely covering the CFC-113 peak, we could not determine
CFC-113 peak area and give flag “5”.

Precisions

The analytical precisions were estimated from replicate sample analyses. The replicate samples were basically
collected from two sampling depths which is around 250 m and 800 m depth. Because lateral and vertical variations
of CFC concentrations were very large, CFC data were divided into two groups for the estimation based on
concentration ranges, i.e. high concentration group which was more than 1.0 pmol kg⁻¹ of CFC-11 and -12 and 0.1
pmol kg⁻¹ of CFC-113 and low concentration group which was below the above concentrations. The precisions were
estimated by two methods. One (A) is estimated by following equation, \( s = \left( \frac{\sum (\Delta C)^2}{2n-1} \right)^{0.5} \), where \( \Delta C \) is
difference between replicate analyses (Table 1). Another (B) is average difference of replicate analyses (with
standard deviation, SD) (Table 2).

<table>
<thead>
<tr>
<th>CFCs</th>
<th>Conc. Range</th>
<th>Mean (SD)</th>
<th>Precisions</th>
<th>Data number</th>
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<tr>
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<td>(pmol kg⁻¹)</td>
<td>(pmol kg⁻¹)</td>
<td>(pmol kg⁻¹)</td>
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</tr>
<tr>
<td>CFC-11</td>
<td>Whole</td>
<td>1.33 (1.13)</td>
<td>0.008</td>
<td>219</td>
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<tr>
<td></td>
<td>≥ 1.0</td>
<td>2.17 (0.80)</td>
<td>0.009</td>
<td>121</td>
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<tr>
<td></td>
<td>&lt; 1.0</td>
<td>0.29 (0.29)</td>
<td>0.005</td>
<td>98</td>
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<td>CFC-12</td>
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<td>0.71 (0.61)</td>
<td>0.006</td>
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<tr>
<td></td>
<td>≥ 1.0</td>
<td>1.46 (0.33)</td>
<td>0.008</td>
<td>69</td>
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<tr>
<td></td>
<td>&lt; 1.0</td>
<td>0.36 (0.34)</td>
<td>0.005</td>
<td>150</td>
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<tr>
<td>CFC-113</td>
<td>Whole</td>
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<td>0.005</td>
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<td>≥ 0.1</td>
<td>0.20 (0.08)</td>
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<td>&lt; 0.1</td>
<td>0.04 (0.02)</td>
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Table 1. Analytical precisions of CFC concentrations estimated from method (A).
Table 2. Analytical precisions of CFC concentrations estimated from method (B).

<table>
<thead>
<tr>
<th>CFCs</th>
<th>Conc. Range</th>
<th>Mean (SD) (pmol kg(^{-1}))</th>
<th>Precisions (SD) (pmol kg(^{-1}))</th>
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<td></td>
<td>&lt; 0.1</td>
<td>0.04 (0.02)</td>
<td>0.004 (0.005)</td>
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</tbody>
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Reference


3.9 Lowered Acoustic Doppler Current Profiler

25 August 2006

(1) Personnel
Shinya Kouketsu (JAMSTEC)
Yasushi Yoshikawa (JAMSTEC)

(2) Instrument and measurement
Direct flow measurement from sea surface to the bottom was carried out using a lowered acoustic Doppler current profiler (LADCP). The instrument used was the RDI Workhorse Monitor 307.2 kHz unit (RD Instruments, USA). The instrument was attached on the CTD/RMS frame, orientating downward. The CPU firmware version was 16.05. The firmware was updated at station P10-002 to version 16.27.

One ping raw data were recorded. Settings for the collecting data are listed in Table 3.9.1. A total of 128 operations were made with the CTD observations. The performance of the LADCP instrument was good in northern stations (in the subarctic region of North Pacific). Profiles were obtained over 100 m distance from LADCP in shallow depth and almost 60 m in deeper depth. On the other hand, the performance was bad in southern stations in the subtropical region of North Pacific. In the deeper depth, good quality data were obtained only 3 or 4 bins, which means the LADCP could observe only about 25 m. It would due to a weak echo intensity, which agreed with ship’s ADCP. Data transfer errors were often occurred during upload process from the LADCP to PC.

(3) Data process and result
Vertical profiles of velocity are obtained by the inversion method (Visbeck, 2002). Both the up and down casts are used for the inversion. Since the first bin from LADCP is influenced by the turbulence generated by CTD frame, the weight for the inversion is set to small value of 0.1. The GPS navigation data are used in the calculation of the reference velocities and the bottom-track data are used for the correction of the reference velocities. Shipboard ADCP (SADCP) data averaged for 3 minutes are also included in the calculation. The CTD data are used for the sound speed and depth calculation. IGRF (International Geomagnetic Reference Field) 10th generation data are used for calculating magnetic deviation to correct the direction of velocity. In the processing, we use Matlab routines provided from M. Visbeck and G. Krahmann (http://ladcp.ldeo.columbia.edu/ladcp/).

Figure 3.9.1 and 3.9.2 show the results of the cross-section velocity (eastward is positive) and the along-section velocity (northward is positive). The major currents in the Western Pacific such as the Kuroshio Extension (P10N-116-114), the Equatorial Under Current (around P10-18), and New Guinea Coastal Under Current (P10-002) appeared in the figures. Figure 3.9.3 shows error velocity estimated by the inversion method. The error velocities are very small (less than 5 cm/s) upper 1000 dbar and adjacent to the bottom. Since the absolute velocities are obtained only by LADCP data from bottom track, the error velocity near the bottom is small. Upper 1000 dbar, the error velocity is small due to SADCP data. The velocity profile obtained from LADCP without SADCP resembles the one from SADCP. The uncertainty of velocity from SADCP is about 10 cm/s. So we think the error velocity from LADCP upper 1000 dbar is about 10 cm/s. The error velocities are less than 10 cm/s on the northern side of the Kuroshio Extension. However, error velocities are large in the subtropical gyre. It is probably due to the short range of the LADCP signal, which makes the shears suspicious. In the estimation of the velocity from LADCP data, it is the biggest problem that there is less information of the CTD frame motion, which is only determined from bottom track data and GPS data.

---

Table 3.9.1. LADCP Settings for the collecting data.

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<td>20</td>
<td>16</td>
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68
Reference

Figure 3.9.1. The cross-section of zonal velocity (eastward is positive).

Figure 3.9.2. The cross-section of meridional velocity (northward is positive).

Figure 3.9.3. Cross-section of error velocity estimated by the inversion method.
<table>
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<th>Station Summary</th>
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**Comments:**
- FOR SOUND SPEED CORRECTION, TSK T-7
- REPLACED Y-CABLE
- REMOVED FLUOROMETER, #11 MISS FIRE
- RAIN SAMPLING (1.2MM/HR)
- RAIN SAMPLING (14.0MM/HR)
| Parameter number: | 1=SALNTY, 2=OXYGEN, 3=SILCAT, 4=NITRAT, 5=NITRIT, 6=PPHSPHT, 7=CFC-11, 8=CFC-12, 12=DELC14, 13=DELC13, 22=CS-137, 23=TCARB, 24=ALKALI, 26=PH, 27=CFC113, 30=NH4, 34=CHLORA, 41=PON, 47=P|
Figure captions

Figure 1  Station locations for WHP P10 revisit cruise with bottom topography based on Smith and Sandwell (1997).

Figure 2  Bathymetry measured by Multi Narrow Beam Echo Sounding system. Cross mark indicates CTD location.

Figure 3  Surface wind measured at 25 m above sea level. Wind data is averaged over 1-hour and plotted every 0.5 degree in latitude.

Figure 4  Sea surface temperature (SST) and salinity (SSS). Temperature and salinity data are averaged over 1-hour.

Figure 5  Difference in the partial pressure of CO₂ between the ocean and the atmosphere, \( \Delta p_{\text{CO}_2} \).

Figure 6  Surface current at 100 m depth measured by shipboard acoustic Doppler current profiler (ADCP).

Figure 7  Potential temperature (°C) cross section calculated by using CTD temperature and salinity data calibrated by bottle salinity measurements. Vertical exaggeration of the 0-6,500 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  Same as Figure 8 but with SSW batch correction.

Figure 10  Density (\( \sigma_0 \)) (kg/m³) cross section calculated using CTD temperature and calibrated salinity data with SSW batch correction. Vertical exaggeration is same as Figure 7.

Figure 11  Same as Figure 10 but for \( \sigma_\theta \) (kg/m³).

Figure 12  Neutral density (\( \gamma_n \)) (kg/m³) cross section calculated using CTD temperature and calibrated salinity data with SSW batch correction. Vertical exaggeration is same as Figure 7.

Figure 13  Cross section of bottle sampled dissolved oxygen (\( \mu \text{mol/kg} \)). Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 14  Silicate (\( \mu \text{mol/kg} \)) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 15  Nitrate (\( \mu \text{mol/kg} \)) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration of the upper 1000 m section is same as Figure 7.

Figure 16  Nitrite (\( \mu \text{mol/kg} \)) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 17  Phosphate (\( \mu \text{mol/kg} \)) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 18  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 19  Total alkalinity (\( \mu \text{mol/kg} \)) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 20  pH cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 21  CFC-11 (pmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.
Figure 22  CFC-12 (pmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 23  CFC-113 (pmol/kg) cross section. Data with quality flags of 2 were plotted. Vertical exaggeration is same as Figure 7.

Figure 24  Cross section of current velocity (cm/s) normal to the cruise track measured by LADCP (eastward is positive).

Figure 25  Difference in potential temperature (°C) between results from WOCE (from Oct. to Nov., 1993) and the revisit cruise (from May to Jul., 2005). Red and blue areas show the areas where potential temperature increased and decreased in 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 26  Difference in salinity (psu) between results from WOCE and the revisit cruise. Red and blue areas show the areas where salinity increased and decreased in the revisit cruise, respectively. CTD salinity data with SSW batch correction¹ are used. On white areas differences in salinity do not exceed the detection limit of 0.002 psu. Vertical exaggeration is same as Figure 7.

Figure 27  Difference in dissolved oxygen (µmol/kg) between results from WOCE and Revisit. Red and blue areas show the areas where salinity increased and decreased in the revisit cruise, respectively. CTD oxygen data are used. On white areas differences in salinity do not exceed the detection limit of 2 µmol/kg. Vertical exaggeration is same as Figure 7.

Note
1. As for the traceability of SSW to Mantyla’s value, the offset for the batches P114 (WOCE P10), and P145 (Revisit) is +0.0007 and -0.0013, respectively (Kawano et al., 2006).

References


Figure 1

Station locations for WHP P10 revisit cruise
Figure 2

Bathymetry measured by Multi Narrow Beam Echo Sounding system
Figure 2

continued
Figure 3

Surface wind measured at 25 m above sea level
Figure 4

Sea surface temperature (SST) and salinity (SSS)
Figure 5

$\Delta p\text{CO}_2$
Surface current measured by shipboard ADCP
Figure 7

Potential temperature (°C)
CTD salinity (psu)
Figure 9

CTD salinity (psu) with SSW batch correction
Figure 10

Density ($\sigma_0$) (kg/m$^3$)
Figure 11

Density ($\sigma_4$) (kg/m$^3$)
Figure 12

Neutral density ($\gamma^n$) (kg/m$^3$)
Figure 13

Bottle sampled dissolved oxygen (μmol/kg)
Figure 14

Silicate (μmol/kg)
Figure 15

Nitrate (μmol/kg)
Figure 16

Nitrite (μmol/kg)
Figure 17

Phosphate (μmol/kg)
Figure 18

Dissolved inorganic carbon (µmol/kg)
Figure 19

Total alkalinity (µmol/kg)
Figure 20

pH
Figure 21

CFC-11 (pmol/kg)
Figure 22

CFC-12 (pmol/kg)
Figure 23

CFC-113 (pmol/kg)
Figure 24

Current velocity (cm/s) normal to the cruise track measured by LADCP (eastward is positive)
Figure 25

Difference in potential temperature (°C) between results from WOCE and the revisit cruise
Figure 26

Difference in salinity (psu) between results from WOCE and the revisit
Figure 27

Difference in dissolved oxygen (µmol/kg) between results from WOCE and the revisit.
WHP P10 REVISIT DATA BOOK

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Extended northern end up to Hokkaido

in 2005