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R/V Mirai Cruise Report
MR01-K04 Leg.1

25.July-28.August, 2001

Japan Marine Science and Technology Center

(JAMSTEC)

Contents

1. Preface

The first leg of MR01K04 cruise started at Sekinehama, Aomori on 25 July 2001. The main purpose of the cruise was to re-visit one of WHP sections of P17N which was occupied across the Gulf of Alaska in 1993 by United States and Canada. After the construction of R/V Mirai, new organization of Marine Work Japan and Global Ocena Development Inc. were established to take a large part in the observational activities of JAMSTEC on R/V Mirai. The hydrographic observation of WHP type, including data collection and data handling, which was carried out during this cruise was the first experience not only for those organizations but also for most of researchers in JAMSTEC and R/V Mirai herself.

After a month's straggle 76 high-quality hydrographic stations were occupied. Carbonated chemistries were analyzed newly. The accuracy of CTD measurement including analysis of bottle salinity and DO were same as or better than the WOCE criteria. Apart from WHP action above, Ocean bottom electric meter was deployed and bio-environmental research was carried out also during the period of the first leg.

The cruise finished at Dutch Harbor on 27 August. On behalf of all scientists, I would like to express heartfelt thanks to crew of Mirai from Global Ocean Development Inc. under captain Akamine, technicians from Marine Works Japan. Thanks are also extended to the research support division of JAMSTEC under Mr. Itoh.

MR01K04 the first leg Chief Scientist
Masao Fukasawa
Japan Marine Science and Technology Center

2. Outline of the first leg of MR01K04

The main purpose of the first leg of MR01K04 was to study the heat and material transport including their time changes by ocean general circulation. 63 XCTD stations were located across the Pacific and 77 CTD/RMS stations including 18 biological sampling and UV photometer lowerings were occupied along WHP P17N in the Gulf of Alaska. Cruise track is shown in figure 1 with these XCTD and CTD/RMS stations. Also the .sum file can be found in appendix of this section.

The cruise started on 24 July 2001(UTC). After a free fall of CTD cable and a biological sampling at Kasima trench (Stn401), the trans-Pacific XCTD casting started (Stn402). On 27 Jul. the Ocean Bottom Elecromagneticmeter was deployed and a biological sampling was carried out with a UV photometer loweing (Stn415). In the course of the trans Pacific track, two CTD/RMS training stations were occupied (Stns. 431 and 454). On these stations, also biological sampling and UV photometer lowerings were carried out. On 6 Aug. the cruise entered the WHP P17 revisit part at Stn26, the northernmost part of P17C. After 51 stations were occupied, we encountered a strong low on 20 Aug. Extremely severe sea condition interrupted the observation for 48 hours. Even after the storm, the sea condition remained bad and the speed of the CTD lowering had to be slown down. As the result, we gave up five CTD/RMS stasions (Stns 85, 89, 91, 95 and 97), however two of them were back up by XCTD (Stns 95 and 97). The cruise finished on 27 Aug. with the bottom-track calibration of ADCP6 hours before Mirai called a port at Dutch Harbor.

In the first leg of MR01K04, scientists were engaged in six major scientific projects. They will be tabulated with each brief explanation here. Detailed report for each project can be referred to in following sections. Underway obseravation data including meteorological ones are included in the section of 'Water mass structure in the Sub-arctic gyre' section.

１） Ocean Hemisphere Network Project

Installation of SeaFloor ElectroMagnetic Station in Northwest Pacific.

２） Atmospheric and Upper Ocean Geochemistry

Study on the transport mechanism of Asian dust and their impact on marine environment of North Pacific.

３） Effect of ultraviolet radiation on phytoplankton

Study on the effect of the ultraviolet on the phytoplankton which supports the ecosystem of the ocean

４）Development of the Ocean LIDAR

To develop the LIDAR, laser radar, to detect a horizontal distribution of phytoplankton and a vertical distribution of suspended matters.

５）Measuremant of the atmospheric optical thickness

To clear and solve the problems of horizontal distribution and optical properties of aerosols, some observations were carried out over the sub-polar region of the North Pacific Ocean.

６）Water mass structure in the Sub-arctic gyre

To study the water mass structure in the transition zone between the sub-arctic and sub-tropical gyres along the trans-Pacific track. Revisit of P17N to detect long-term changes in the ocean structure.

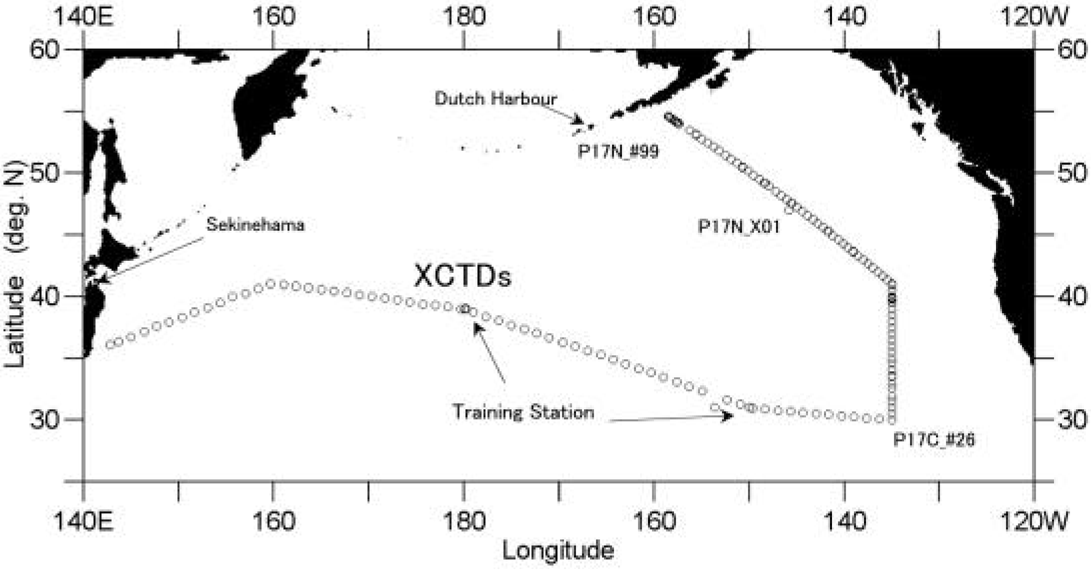

Figure 1: Station locations of MR01K04

3. Detailes of research

3-1 Installation of SeaFloor ElectroMagnetic Station in Northwest Pacific During MR01K04

- Ocean Hemisphere Network Project -

Hiroaki TOH(1), Sawako HOMMA(1) and Hisayoshi SHIMIZU(2)

(1) Department of Earth Sciences, Toyama University
(2) Earthquake Research Institute, University of Tokyo

1. Objectives

To study the structure and dynamics of the Earth's interior requires geophysical data taken at the stations distributed well over the surface of the Earth. However, ocean area has been a big blank window where not many geophysical, especially long-term, observations have been conducted. To install a SeaFloor ElectroMagnetic Station (SFEMS) is a part of the Ocean Hemisphere Project (OHP). The project aims at obtaining new sets of seismic, geodetic and geomagnetic information in the Pacific area to study deep interior of the Earth.

Installing the SFEMS in the northwest Pacific is two fold. One is to obtain local electrical conductivity structure to study the tectonics of the area and the dynamics of the mantle. The other is to fill the blank area of existing geomagnetic observatories for a better understanding of the global feature of the geomagnetic field. This will facilitate the study of the dynamics of the outer core of the Earth where the geomagnetic field is generated. Very long-term observations are indispensable for this purpose.

One of the long-term goals of the project is to establish a permanent geomagnetic station network at the seafloor. The installation of the SFEMS is the first step towards the goal.

We will report on the installation of the SFEMS in the following.

2. Installation of SeaFloor ElectroMagnetic Station

A system of SFEMS (Figure 1), a long-life self-contained pop-up type instrument, was deployed in Leg1, on July 27, 2001 (UT). The SFEMS consists of an Overhauser absolute scalar magnetometer, a three-component fluxgate magnetometer, a horizontal two-component voltmeter, two tilt meters and a fiber-optical gyroscope. This system will be recovered next year, after one-year operation on the seafloor.

The observation parameters were set as follows (all time in UT):

General setting :
    Start time of the measurement: Aug.1, 2001
    Sampling interval = 60 seconds
Gyroscpoe :
    Latitude : 41 deg 07 min
    Operation #1 Oct.1, 2001 00:00- [28hours]
    Operation #2 Jan.1, 2002 00:00- [28hours]
    Operation #3 Apr.1, 2002 00:00- [28hours]
Overhauser magnetometer:
    tuning value=44000 nT (from IGRF2000)

Stability of the electrodes for electric field measurement was tested before deployment. Figure 2 shows the self potential of electrodes against electrode C1. Since absolute value of the self potential of C2 was larger than the others, the electrode was not employed for observation. Also, C8 was excluded due to large trend. Final decision of the electrodes was North=C3, South=C10, East=C4, West=C7, and GND=C5.

The SFEMS was deployed successfully at 22:08 on July 27, 2001 (UT). The location of deployment was 41deg 07.0133min N, 159deg 56.0077min E. The ocean depth measured by ship's SeaBeam was 5615m. The descending process was monitored by acoustic ranging. A trial to utilize the transducer equipped on the ship for acoustic communication was made. The transducer was connected to a Kaiyo Denshi on board unit via a matching box. The communication between the ship-unit and SFEMS went well at the beginning, until the SFEMS reached the depth 1097m. However, no communication was established after that probably due to lack of sound pressure produced by the Kaiyo Denshi unit. Another transducer unit made by Nichiyu Giken was used for the ranging afterwards. The results are summarized in Table 1. Estimated average descending speed is 42.8m/min.

Acoustic ranging to determine the position of the SFEMS on the seafloor was also conducted. The measurements were made at 7 locations on the sea surface, the point of deployment and 6 points equally distributed on the circle of radius about 3km, of its center at the point of deployment. See Figure 3 for the locations. Results of the ranging are listed in Table 1. The determined position of the SFEMS is 41deg 07.0679 min N, 159deg 55.1762min E, and depth=5600 m. The site is about 500m west and 140m north from the point of deployment. Note that the sound velocity profile provided by GODI and shown in Figure 4 was used for the calculation.

Table 1. Summary of acoustic ranging

Time(UT)	Latitude	Longitude	Depth(m)	Slant Range(m)	Notes	Deck Unit
July 27.						
22:08	N41 07.0133'	E159 56.0077'	5616		deployment	
22:16				453		Kaiyo Denshi
22:26				880		Kaiyo Denshi
22:31					low power	Kaiyo Denshi
22:32				1057	high power	Kaiyo Denshi
22:33				1097		Kaiyo Denshi
22:36					NG	Kaiyo Denshi
22:38					NG	Kaiyo Denshi
23:08				2550		Nichiyu Giken
23:38				3730		Nichiyu Giken
23:55				4410		Nichiyu Giken
July 28.						Nichiyu Giken
0:10				5216		Nichiyu Giken
0:30	N41 06.7030'	E159 55.9257'		5641	SFEMS landed	Nichiyu Giken
0:49	N41 06.9938'	E159 56.0742'	5616	5613	Ranging site1	Nichiyu Giken
1:22	08.5691'	56.1554'	5608	6186	Ranging site2	Nichiyu Giken
1:55	07.5912'	57.7249'	5589	6340	Ranging site3	Nichiyu Giken
2:27	06.0319'	57.8492'	5611	6691	Ranging site4	Nichiyu Giken
3:02	05.2957'	56.8997'	5584	6542	Ranging site5	Nichiyu Giken
3:31	06.1794'	54.0703'	5601	6315	Ranging site6	Nichiyu Giken
4:02	07.7945'	54.0852'	5601	6151	Ranging site7	Nichiyu Giken

* All positions are based on the WGS84 geodetic reference frame.

Figure 1. SeaFloor ElectroMagnetic Station before deployment

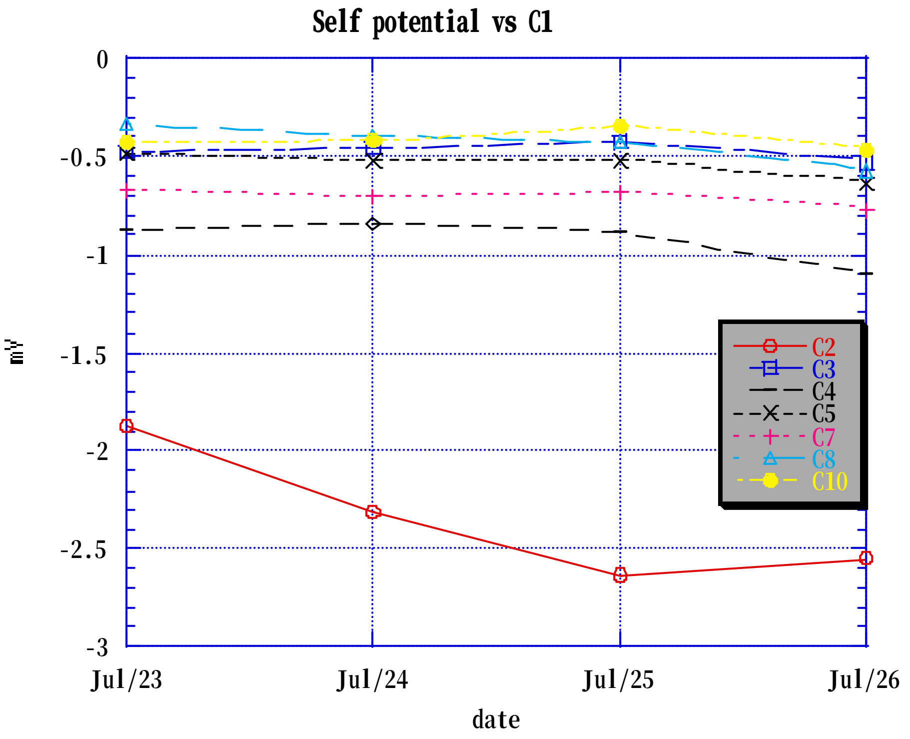

Figure 2. Variation of self potential of electrodes against C1

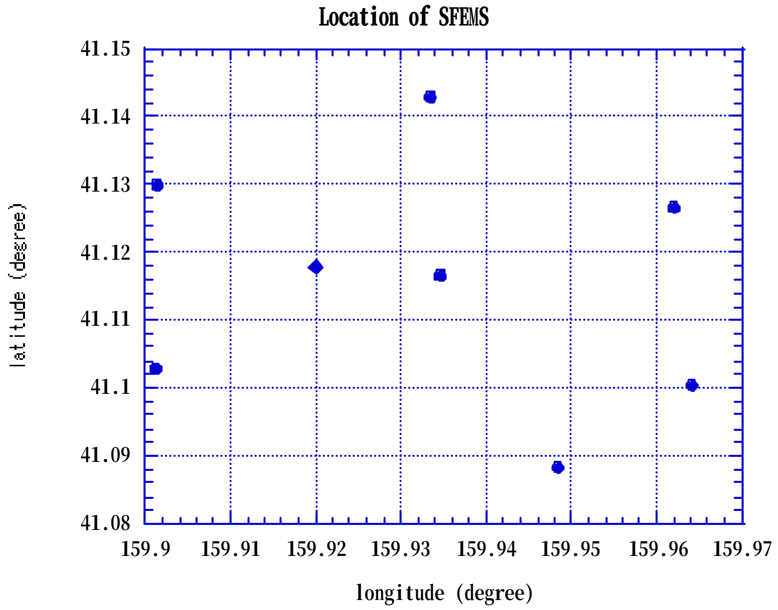

Figure 3. Observation points for acoustic ranging ● and determined position of SFEMS ◆.

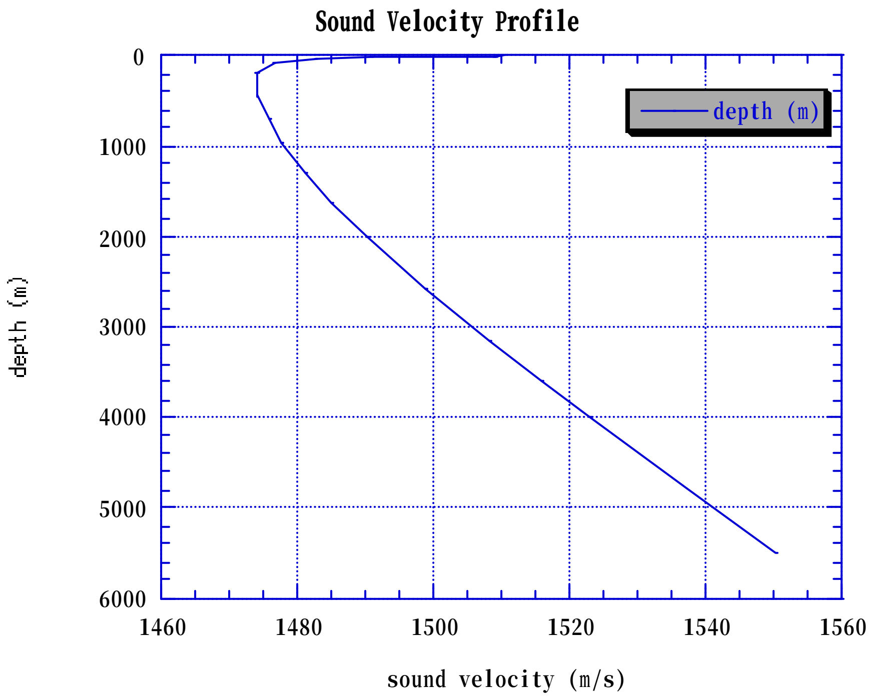

Figure 4. Sound velocity profile used to calculate the location of SFEMS

3.2 Atmospheric and Upper Ocean Geochemistry

-Transport mechanism of Asian dust and their impact on marine environment of North Pacific-

(1) Personal (Leg1)

Mariko Hatta(Toyama University)

Co-workers not on board:
Jing ZHANG and Jiahong WU (Toyama University)

(2) Introduction

It is well known that the exchange of material and energy between the atmosphere and ocean has especially significance. Global geographical and seasonal distributions of troposphere aerosol have attracted considerable attention during the past several decades. The natural aerosol has been substantially perturbed by anthropogenic activities, e.g. increases of sulfates, nitrates, organic condensates, soot, and soil dusts. Since the long-range transport of anthropogenic aerosols from East Asia have important influence to the bio-geochemical environments of high latitude northern Pacific Ocean, it is of great moment to elucidate the chemical properties of aerosols and there transportation over the Ocean. In order to investigate the origin and elucidate the transport mechanism of the aerosol from Asian continent, the aerosol sampling and measurements were carried out in this study. In addition, surface seawater and particulate matter were also collected to analysis.

(3) Objectives

The aerosols were collected by using a high volume sampler equipped by four respective grain diameter for particals, , with the purposes are:

1) To investigate the origin and elucidate the transport mechanism of the aerosol from Asian continent.
2) To demonstrate the nutrient transportation by dust between the continent and open Ocean, and calculate the budget of their fluxes.
3) To illuminate clarify the REE fractionation between the dissolved and particular particulate phases in the surface seawater, and comprehending thus gain an understanding of their physical-chemical reactions during the scavenging process.

(4) Instruments and Analytical Methods

1. Aerosol collection :

The aerosols were collected by using a high volume sampler (AH-600, SHIBATA Co.) on the compass deck during this cruise from July 24, to Augest 5, 2001 (Table1.). Aerosols were collected on quartz fiber filters while the vessel is sailing, the pumping time for each collector is about 30 hours and the flow rate is about 1100±13L/min (19℃).

Table1. Atmospheric sample

July 24 ~ July 26	July 29 ~ July 30(A)	July 31 ~ Aug 2	Aug 3 ~ Aug 5
July 26 ~ July 28	July 30(A) ~ July 31	Aug 2 ~ Aug 3	

2. Analysis of the aerosol:

Each filter was divided after collection and the one-forth of it was extracted by 40ml model seawater for nutrient analysis. Nutrients (nitrite, nitrate, phosphate, silicate) were determined on boat. The remainder will transfer to the laboratory on land for mineral composition examine.

3. Surface seawater and the particle ：

Surface seawaters, about 20 litters each, from 17 stations (table 2) were collected by pre-cleaned bucket for dissolved REE determination. Immediately after collection, all seawater samples (2 litters) were filtered through 0.1 μm membrane filters. The resides with filters were stored in refrigerator, and filtrate were acidified to pH<1.6 for analysis on land in the near future.

Table2. Seawater samples for rare earth elements by bucket

CTD test	P1726	P1744	P1774
SFEMS	P1721	P1751	P1781
Train1	P1729	P1758	P1792
Train2	P1734	P1765	

(5) Data Archive

All of the raw and processed data of atmospheric and seawater will be submitted to the JAMSTEC Data Management Office (DMO) as soon as analysis is completed and will remain under its control.

3.3 Effect of ultraviolet radiation on phytoplankton assemblages in the North Pacific Ocean

(1) Personnel

Nozomi FUKUSHIMA(Soka university)：Leg1,2
Tokue TAKANO(Soka university)：Leg1,2

(2) Introduction

Since underwater instrument has been developed recently to determine a penetration of ultraviolet radiation, the penetration characteristics have been recognized in various waters. Ultraviolet radiation-B (UV-B) can penetrate even to a deep part of euphotic zone. The decrease of ozone concentration has enhanced the penetration of ultraviolet radiation. Phytoplankton seems to be suffered from the deeply penetrated ultraviolet radiation.

It is important to investigate the effect of the ultraviolet radiation on the phytoplankton which supports the ecosystem of the ocean.

(3) Objectives

The effect of the ultraviolet radiation on the phytoplankton in the North Pacific Ocean is evaluated by the following objectives;

A) Shipboard experiment of photosynthesis curve (P vs I curve) is carried out using surface sea water in order to evaluate the effect of the ultraviolet radiation on the photosynthesis of phytoplankton.

B) The 24 hour incubation experiment is carried out using surface radiation on sea water on board in order to evaluate the effect of the ultraviolet radiation on pigments and DNA of phytoplankton.

(4) Materials and Methods

A) Observation of ultraviolet radiation quantity and photosynthetically available radiation (PAR)

Ultraviolet radiation in air and PAR were observed continuously on the deck. Underwater ultraviolet radiation and PAR were measured at stations (Table 1).

B) Photosynthesis experiment (P vs I curve).

Surface waters (40L) were sampled in the morning by the bucket at stations (Table 2), and P vs I curve experiment was carried out.

Surface water sample was distributed to 10 light bottles and 1 darkness bottle, and NaH13CO3 aqueous solution was inoculated to start the incubation experiment for 3 h at surface water temperature. Subsamples for chlorophyll pigments particulate organic carbon (POC), was collected. Subsamles for nutrient and microscopic observation were collected at time zero.

C) Simulated *in situ* incubation experiment.

Surface sea water (100〜140L) was collected at station before sunrise (Table 3). The culture bottle, the quartz bottle and the acrylic container were used. The each container was cultivated in incubator installed on the deck for 24 hours.

Subsamplesfor pigments, POC, PON, size fractionation of phytoplankton, DNA were collected at the beginning and end of the incubation. Subsamples for nutrient microscopic observation were also collected.

Table 1. Sampling location for ultraviolet radiation and PAR observation.

Train2	P1726	P1721	P1726	P1718	P1735
P1750	P1759	P1765	P1773	P1783	

Table 2. Sampling location for P vs I curve experiment.

SFEMS	Train1	Train2	P1726	P1718	P1735
P1750	P1759	P1765	P1773	P1783	

Table 3. Sampling location for simulated *in situ* incubation experiment.

Train1	Train2	P1723	P1734	P1749	P1758
P1773	P1783				

5) Data sharing.

All samples will be analyzed as soon as possible and made available for the public.

3.4 Ocean Lidar

Takeshi Kawano JAMSTEC, Ocean Research Department
Ai Yasuda, MWJ
Yuichi Sonoyama, MWJ

1.Objectives

The LIDAR, laser radar, has been developed to detect a horizontal distribution of phytoplankton and a vertical distribution of suspended matters. In order to check the performance of the system and get the required parameters for the system, continuous measurements were made.

2.Method

(1) Ocean Lidar

The LIDAR operates a Nd.YAG laser, which emits a green pulse laser in 532 nm through KDP crystal as the second harmonic of Nd.YAG. Detectors in this system detects the laser excited fluorescence from phytoplankton in the surface layer and the light scattered by particles from the depth of about 5O meters. A density of chlorophyll-a is estimated through the empirical equation, obtained by a least square method. A vertical distribution of phytoplankton will be estimated from the logarithm decrement of signal as a function of particles.

(2) Sea truth data

In order to compare the data from Ocean Lidar system, we made an observation as follows.

-Chlorophyll-a

Surface seawater was sampled every 4 hours to measure Chlorophyll-a.

- Photosynthetic parameters

We made an P-I curve measurement in every 8 hours using a surface seawater. The bottles were spiked with 0.2 mmoles/mL of $NaH^{13}CO_3$ solution, and incubated for 3 hours at temperature- controlled bath in a laboratory. The light intensity was shown in table 1. Samples were filtered immediately after the incubation and the filters were kept to freeze till analyse of this cruise. After that, filters were dried on the oven of 45 degree C.

Figure. 1 shows a time series of Laser-excited fluorescence along with the measured chlorophyll-a. X-axis is date and Y-axis is Chl-a and Fluorescence. Circles represent the chlorophyll-a measured by Turner fluorometer and line represents fluorescence measured by Ocean Lidar system. Qualitatively, both values agree well.
Other data such as P-I curve, will be analyzed after the cruise.

Table. 1 Light Intensity of P-I measurements

Bottle No.	Light Intensity (uE/cm^2/sec)
1	1100
2	500
3	250
4	145
5	70
6	28
7	22
8	12

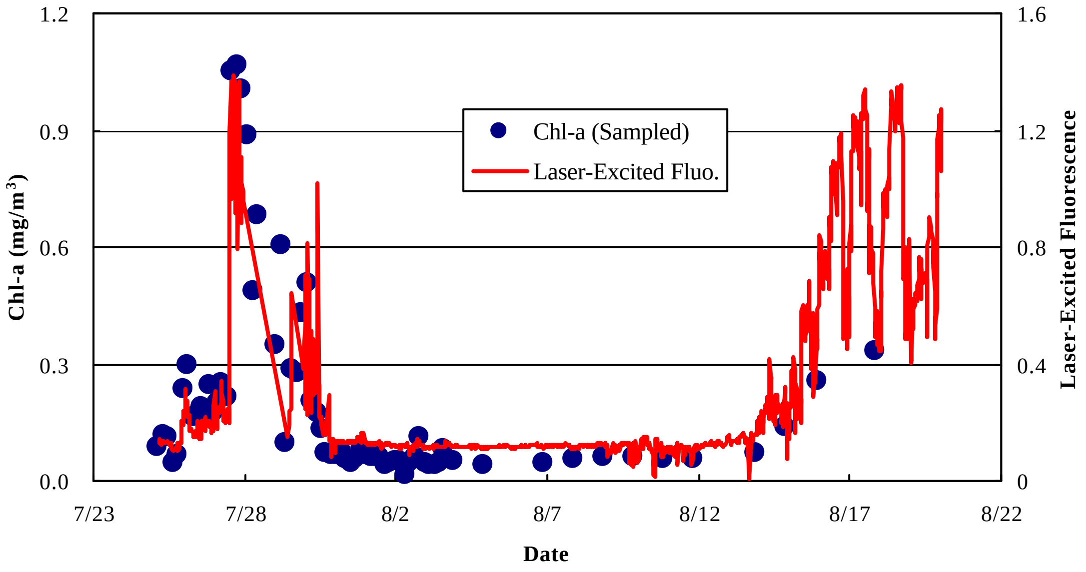

Fig.1 Time Series of Laser-Excited Fluorescence and measured Chlorophyll-a

3.5 Measuremant of the atmospheric optical thickness

(1) Personnel

On board scientists
Tatsuo ENDOH (Institute of Low Temperature Science, Hokkaido University) Associate Professor
Yasushi YOSIKAWA (JAMSTEC) Research Associate
Masao FUKASAWA (JAMSTEC) Chief Research Scientist

Co-workers not on board
Tamio TAKAMURA (Center of environmental remote sensing science, Chiba University) Professor
Sachio OHTA (Engineering environmental resource laboratory, Graduate school of engineering, Hokkaido University) Professor
Teruyuki NAKAJIMA (Center of climate system research, University of Tokyo) Professor

(2) Objects/Introduction

One of the most important objects is the collection of calibration and validation data from the surface (Nakajima et al.1996, 1997 and 1999). It may be considered for the observation over the widely opening of the huge ocean to be desired ideally because of horizontal homogeneity. Furthermore, the back ground values of aerosol concentration are easily obtained over there (Ohta et al.1996, Miura et al. 1997 and Takahashi et al. 1996) and vertical profile of aerosol concentration are obtained by means of extrapolation up to the scale height. It is desired to compare the integrated value of these profile of aerosol concentration with optical thickness observed by the optical and radiative measurement (Hayasaka et al. 1998, Takamura et al.1994). Facing this object, the optical and radiative observations were carried out by mean of the Sky Radiometer providing more precise radiation data as the radiative forcing for global warming.

(3) Measuring parameters

Atmospheric optical thickness, Ångström coefficient of wave length efficiencies, Direct irradiating intensity of solar, and forward up to back scattering intensity with scattering angles of 2-140degree and seven different wave lengths

GPS provides the position with longitude and latitude and heading direction of the vessel, and azimuth and elevation angle of sun. Horizon sensor provides rolling and pitching angles.

Concentration and size distribution of atmospheric aerosol.

(4) Methods

The instruments used in this work are shown as following in Table-1.

Sky Radiometer was measuring irradiating intensities of solar radiation through seven different filters with the scanning angle of 2-140 degree. These data will provide finally optical thickness, Ångström exponent, single scattering albado and size distribution of atmospheric aerosols with a kind of retrieval method.

Optical Particle Counter was measuring the size of large aerosol particle and counting the number concentration with laser light scattering method and providing the size distribution in 0.3,0.5,1.0,2.0 and 5.0 micron of diameter with real time series display graphically.

(5) Results

Information of data and sample obtained are summarized in Table-2. The sky radiometer has been going well owing to more calm and silent condition and circumstances about shivering problems provided by the R/V Mirai whose engines are supported by well defined cushions. Therefore, measured values will be expected to be considerably stable and provide good calculated parameters in higher quality. However, some noise waves were found to interfere the 16,13 and 12channel marine bands of VHF from sky radiometer. Fortunately the origin and source were identified by using a VHF wide band receiver and the interference waves were kept by fairly separating from two VHF antennae and decreased to recovery of 100%.

Aerosols size distribution of number concentration have been measured by the Particle Counter and data obtained are displayed in real time by a kind of time series *in situ* with 5stages of size range of 0.3, 0.5, 1.0, 2.0, and 5.0 micron in diameter.

(6) Data archive

This aerosol data by the Particle Counter will be able to be archived soon and anytime. However, the data of other kind of aerosol measurements are not archived so soon and developed, examined , arranged and finally provided as available data after a certain duration. All data will archived at ILTS (Endoh), Hokkaido University, CCSR(Nakajima), University of Tokyo and CEReS (Takamura), Chiba University after the quality check and submitted to JAMSTEC within 3-year.

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Data inventory

Table-1. Information of obtained data inventory (Method)

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Item, No.data	Name	Instrument	Site position
Optical thickness Ångström exponent.	Endoh	Sky Radiometer(Prede,POM-01MK2)	roof of stabilizer
Aerosol Size distribution	Endoh	Particle Counter(Rion,KC-01C)	compass deck(inlet) & environmental research laboratory

Table-2. Data and Sample inventory

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Data/Sample	rate	site	object	name	state	remarks
Sun & Sky Light	1/5min (fine& daytime)	roof of stabilizer	optical thickness Ångström expt.	Endoh	land analysis	7/24’01-8/27’01
Size distribution of aerosols	1/2.5min	compass deck	concentration of aerosols	Endoh	on board	7/24’01-8/27’01

3.6 Water mass structure in the Sub-arctic gyre

1. Cruise Narrative

1.1 Highlits

WOCE P17N+P17C (eight stations) revisit, R/V Mirai cruise in the Gulf of Alaska

Expedition designation (EXPOCODE): 49MR01K04/1

Chief Scientist:	Masao Fukasawa, Japan Marine Science and Technology Center 2-15, Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan
Ship:	R/V Mirai
Ports of call:	Sekinehama, Japan to Dutch Harbor, U.S.
Cruise dates:	25 July 2001 to 28 August 2001

1.2 Cruise Summary

Number of stations

A total of 78 CTDO/rosette stations including two training stations. CTDO was equipped with LADCP and Transmisson meter. A General Oceanics 36 bottle rosette was equipped with 36 12-liter Niskin-X water sample bottles.

Sampling

The following sample measurements ware made: salinity, oxygen, phosphate, silicate, nitrate, nitrite and CFCs 11, 12 and 113, DIC, pH, alkalinity and delta 14C. CTD salinity and oxygen were also measured.

Overview

The first leg of MR01K04 of R/V Mirai was assigned for WHP P17N revisit cruise. The cruise was planned under a Japanese ocean science program of Sub-Arctic Gyre Experiment (SAGE). SAGE re-occupied P1 (47N) in 1999 and reported preliminarily an evidence of bottom water warming, an anomalously strong intrusion of the meso-thermal water into the Gulf of Alaska and large scale up-welling and down-welling at the mid and deeper depths which was explainable as a local response of the ocean to changes in the wind curl field. The objectives of the cruise were, therefore, focused to detect changes in the bottom and deeper water property and in the temperature stratification at sub-surface compared to the results from P17N in 1993. Beside these physical interests, it was also very important objective of the cruise to collect carbon related parameters which were not measured in 1993.

The cruise stared on 25 July 2001 at Sekinehama port in Mutsu (Figure 1). On the way to the southernmost our WHP revisit station, 64 XCTDs were casted by Japan Fisheries Agency. Also before the first WHP station, two CTD+ROSSET station were occupied for the training of participants. Reference sample water were also collected for radio-active species at one of these stations.

The observation along P17N (+8 stations of P17C) started at P17C_#26 at 19:25 on 6 August 2001. A new DO censer, SBE43, was used in this cruise. The performance of the sensor was so good (Figure 2) that the calibration of the sensor using results from bottle DO measurements can be carried out much easier than before.

A new station of P17N_X01 was added between P17N_#64 and #65 (Figure 2) to occupy P1_#92 which is the crossover station of P17N and P1.

On 24 August, we encountered a big low after the station P17N_#83. The wave height exceeded 5m. R/V Mirai had to make a heaving there for more than 24 hours. This time loss resulted in the replacement of CTD lowering at P17N_#93, #95 and #97 with XCTD casting.

The last station of P17N was occupied at 20:52 on 25 August 2001. We made a port at Dutch Harbor on 28 August.

We would like to express our gratitude to Captain Akamine and all crews of Mirai. Also we would like to express our heartfelt thanks to all participants of this cruise.

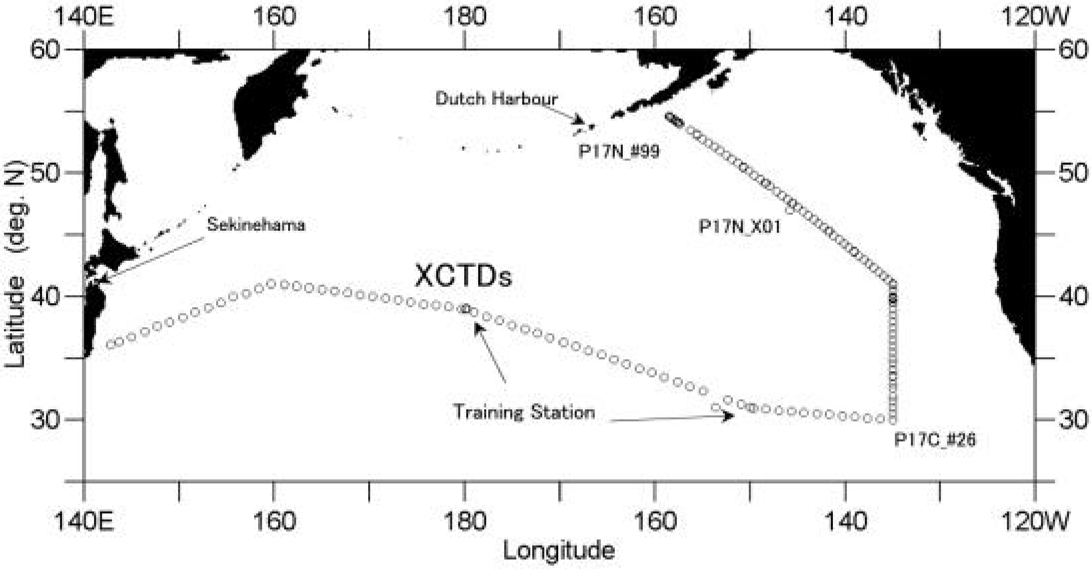

Figure 1: Station locations of MR01K04

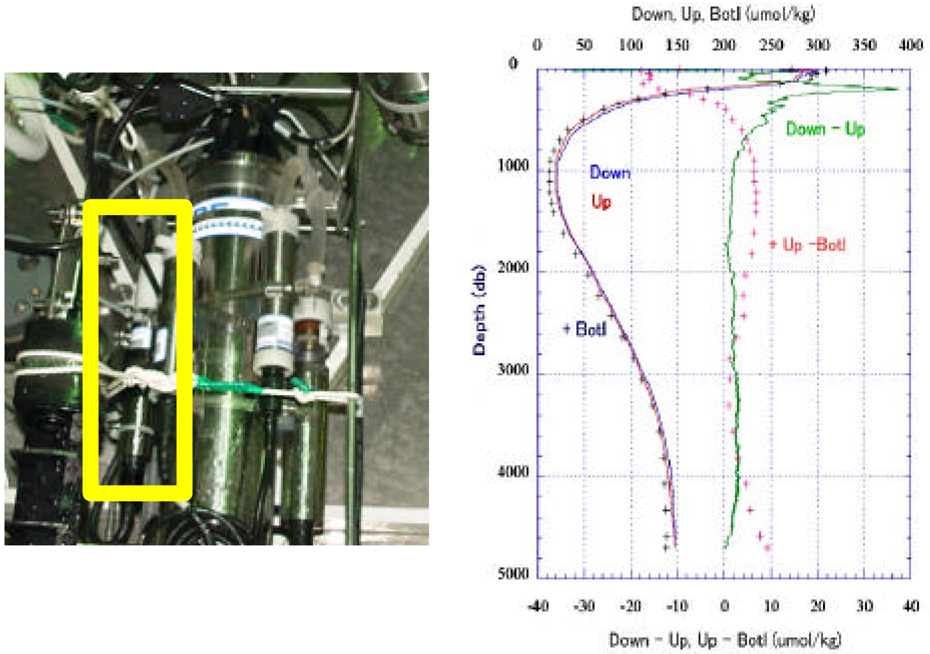

Figure 2: left: SBE43, right: Sensor outputs and bottle measured DO values.

1.3 List of Principal Investigators

The principal investigators responsible for the major parameters measured on the cruise are listed below. Also, the persons responsible for the tasks undertaken on the cruise are listed.

Principal investigator(s)	Person in charge	Responsibility
H. Uchida and M. Fukasawa (JAMSTEC)	S. Ozawa (MWJ)	CTD/O2
Y. Yoshikawa (JAMSTEC)	H. Matsunaga (MWJ)	LADCP
T. Kawano (JAMSTEC)	T. Matsumoto (MWJ)	Salinity
M. Fukasawa (JAMSTEC)	N. Komai (MWJ)	Dissolved oxygen
S. Watanabe (JAMSTEC)	K. Satoh (MWJ)	Nutrients
A. Murata (JAMSTEC)	M. Kitada (MWJ)	DIC
A. Murata (JAMSTEC)	F. Shibata (MWJ)	Total alkalinity
S. Andreev (JAMSTEC)	T. Ohama (MWJ)	pH
Y. Kumamoto (JAMSTEC)	A. Murata (JAMSTEC)	delta14C
S. Watanabe (JAMSTEC)	A. Murata (JAMSTEC)	CFCs
T. Matsumoto (JAMSTEC)	S. Sueyoshi (GODI)	Bathymetry
K. Yoneyama (JAMSTEC)	S. Sueyoshi (GODI)	Meteorology
Y. Yoshikawa (JAMSTEC)	S. Sueyoshi (GODI)	Shipboard ADCP
A. Murata (JAMSTEC)	A. Murata (JAMSTEC)	pCO2
T. Watanabe (TNFRI)	S. Sueyoshi (GODI)	XBT, XCTD
T. Kawano (JAMSTEC)	T. Miyashita (MWJ)	Surface T, S, DO
A. Murata (JAMSTEC)	A. Murata (JAMSTEC)	Surface TCO2

Abbreviations

JAMSTEC: Japan Marine Science and Technology Center
MWJ: Marine Works Japan, Ltd.
GODI: Global Ocean Development, Inc.
TNFRI: Tohoku National Fisheries Research Institute

1.4 List of Cruise Participants

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

Name	Affiliation	Main tasks
Masao Fukasawa	JAMSTEC	LADCP
Yasushi Yoshikawa	JAMSTEC	LADCP
Hiroshi Uchida	JAMSTEC	LADCP
Takeshi Kawano	JAMSTEC	Salinity
Akihiko Murata	JAMSTEC	CFCs
Tomowo Watanabe	TNFRI	XBT/XCTD
Munehito Kimura	KANSO	Nutrients
Takashi Kitao	KANSO	TCO2, CFCs
Nobuharu Komai	MWJ	Oxygen
Satoshi Ozawa	MWJ	CTD operations
Fuyuki Shibata	MWJ	Alkalinity, pH
Katsunori Sagisima	MWJ	Oxygen
Takeo Matsumoto	MWJ	Salinity
Ai Yasuda	MWJ	Nutrients
Mikio Kitada	MWJ	TCO2
Kenichiro Sato	MWJ	Nutrients
Keisuke Wataki	MWJ	Alkalinity, pH
Hiroshi Matsunaga	MWJ	CTD operations
Taeko Ohama	MWJ	Alkalinity, pH
Minoru Kamata	MWJ	TCO2, CFCs
Junko Hamanaka	MWJ	Nutrients
Asako Kubo	MWJ	Nutrients
Yuichi Sonoyama	MWJ	Oxygen
Tomoko Miyashita	MWJ	Oxygen
Naoko Takahashi	MWJ	CTD operations
Shinya Iwamida	GODI	Meteorology, XBT/XCTD
Souichiro Sueyoshi	GODI	ADCP, Bathymetry, XBT/XCTD
Yosuke Inoue	Tokyo University of Fisheries	Water sampling

Hisami Suga	Hokkaido University	Water sampling
Tomokazu Hirata	Tokai University	Water sampling
Fuma Matsunaga	Kagoshima University	Water sampling
Satoko Katsuyama	Tokai University	Water sampling
Tae Yamamoto	Tokai University	Water sampling
Takahiro Miura	Tohoku University	Water sampling

Abbreviations

JAMSTEC: Japan Marine Science and Technology Center
MWJ: Marine Works Japan, Ltd.
GODI: Global Ocean Development, Inc.
TNFRI: Tohoku National Fisheries Research Institute
KANSO: Kansai Environmental Engineering Center Co., Ltd.

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2. Underway Measurements

2.1 Surface Meteorological Observation

Personnel

Kunio YONEYAMA (JAMSTEC)
Shinya IWAMIDA* (GODI)
Souichiro SUEYOSHI* (GODI)

* - Operators on board

Objective

Accurate and continuous surface meteorological measurements are crucial to understand the air-sea interaction quantitatively. These data are used to study the temporal and spatial distribution of the exchange of heat, momentum, and radiation through the sea surface.

Methods

For accurate measurement of surface meteorology on board, in addition to the MIRAI original surface meteorological station (SMET), two state-of-the-art but unique measurement systems are deployed on the R/V MIRAI. One is SOAR (Shipboard Oceanographic and Atmospheric Radiation) measurement system developed by Brookhaven National Laboratory, that focuses on accurate measurement of solar radiation, and the other is turbulent flux measurement system, that measures sensible and latent heat as well as momentum accurately by correcting the influence of ship motion onto the true wind. Sensors of both systems are deployed on the top deck of the foremast, where provides good condition with less influence of ship body dynamically and thermodynamically.

Main components of these systems are listed below (sensor, type, and parameters).

SMET:

Thermometer (Koshin Denki, FT) : air temperature (degC)
Dew point hygrometer (Koshin Denki, DW-1) : dew point (degC)
Anemometer (Koshin Denki, KE-500) : relative wind speed(m/s) and direction(deg)
Barometer (Yokogawa, F451) : pressure(hPa)
Siphonic rain gauge (R.M.Young, 50202) : precipitation (mm)
Optical rain gauge (ScTi, ORG-115DR) : rain rate(mm/hr)
Pyranometer (EKO, MS-801) : downwelling short wave radiation(W/m2)
Pyrgeometer (EKO, MS-200) : downwelling long wave radiation(W/m2)

SOAR (Figure 1) :

T/RH sensor (Vaisala, HMP45A) : temperature(degC), relative humidity(%)
Anemometer (R.M.Young, 5106) : relative wind speed(m/s) and direction(deg)
Barometer (R.M.Young, 61201) : pressure(hPa)
Siphonic rain gauge (R.M.Young, 50202) : precipitation(mm)
Optical rain gauge (ScTi, ORG-115DR) : rain rate(mm/hr)
Portable Radiation Package (BNL, PRP) consists of
  Pyranometer (Eppley, PSP) : downwelling short wave radiation(W/m2)
  Infrared radiometer (Eppley, PIR) : downwelling long wave radiation(W/m2)
  Fast Rotating Shadowband Radiometer (BNL, FRSR) : direct and diffuse components of solar radiation(W/m2)

Data acquisition system (NOAA, SCS:Scientific Computer System)

* Details of the SOAR can be found at http://www.oasd.bnl.gov/

Turbulent Flux measurement system (Figure 2) :

3-D sonic anemometer-thermometer (Kaijo, DA-600) ; wind speed(m/s), temperature(degC)
Infrared hygrometer (Kaijo, AH-300) : specific humidity(g/kg)
Inclinometer (Applied Geomechanics, MD-900-T): hip motion(pitch, roll)
Accelerometer (Applied Signal Inc.,QA700-020): ship motion(acceleration)
Rate gyro (Systron Donner, QRS11-0050-100) : ship motion(angular velocity)

Preliminary results

Original data are taken every 6 seconds for SMET and SOAR, 10Hz for turbulent measurement, respectively, during whole cruise. Time series of basic surface meteorology averaged over one hour are shown in Figure 3.

Data archives

The raw SOAR and SMET data have already been submitted to JAMSTEC Data Management Office(DMO). Corrected data are also available upon request from K.Yoneyama of JAMSTEC and will be available from R.M.Reynolds of BNL. Turbulent flux measurement data, on the other hand, will be processed and archived by O.Tsukamoto of Okayama University. After the processing and quality check, data will be submitted to JAMSTEC DMO and become available at least within 3 years.

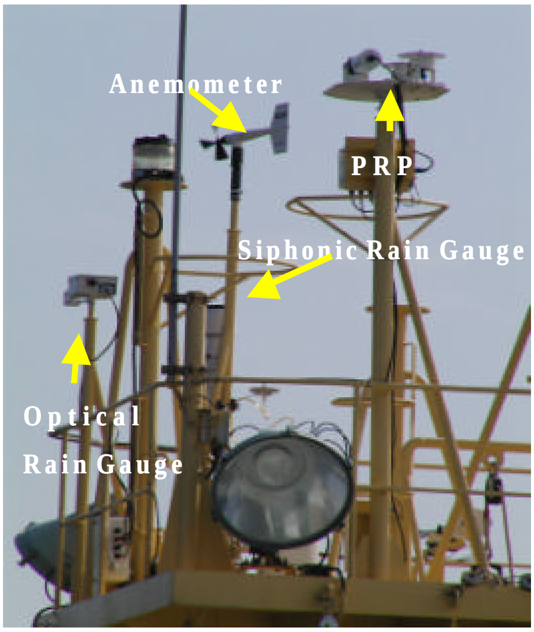

Figure 1: SOAR sensors on the foremast top deck.

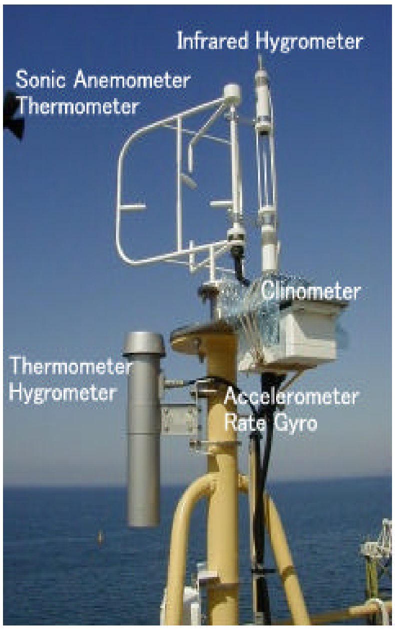

Figure 2: Turbulent flux measurement system

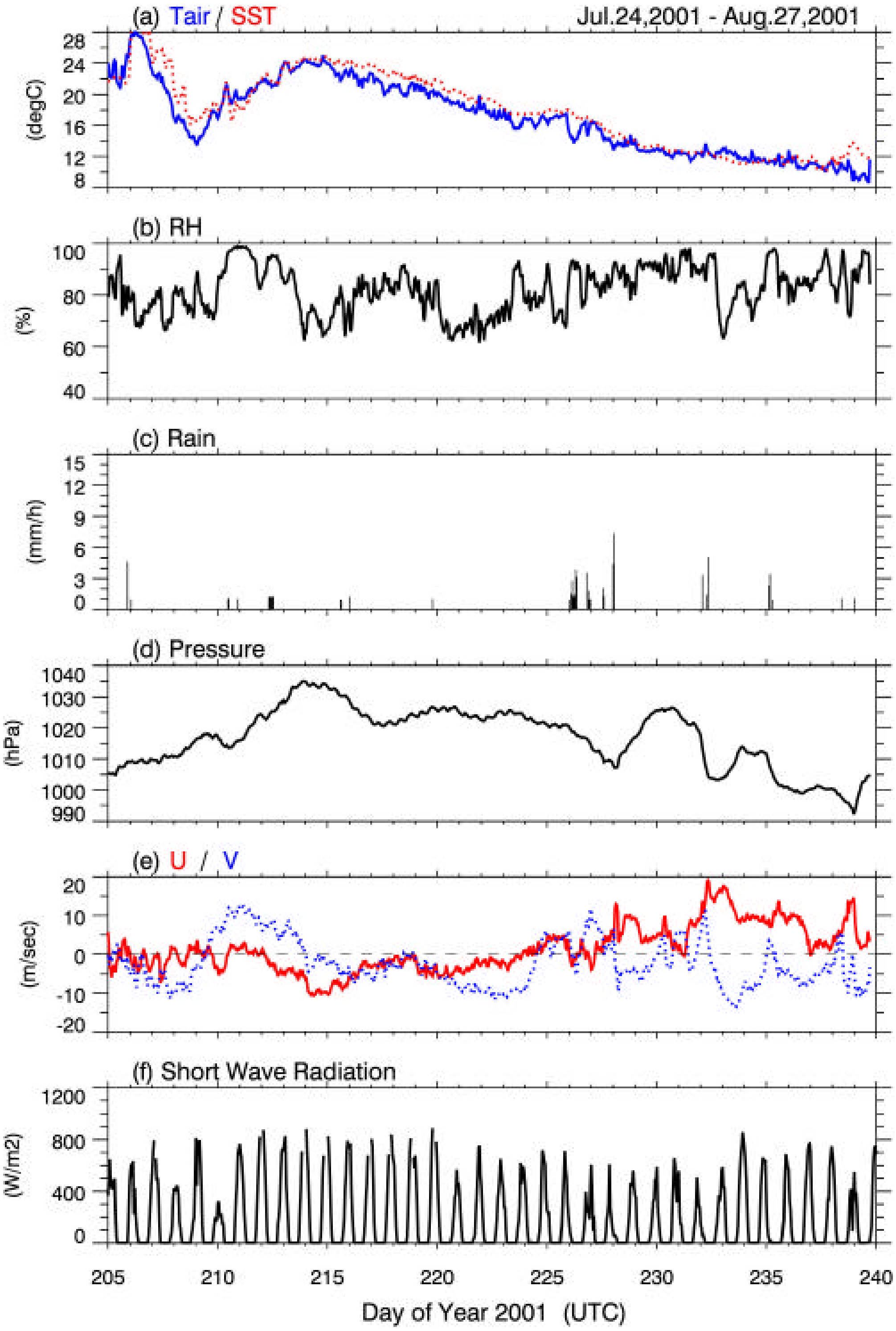

Figure 3: Time series of (a)air temperature and sea surface temperature, (b)relative humidity, (c)rain rate, (d)pressure at sea level, (e) zonal and meridional wind components, and (f) downwelling short wave radiation, respectively.

2.2 Shipboard ADCP Observation

Summary

Direct velocity measurement was made along the cruise track with a hull-mounted ADCP. The ADCP was a 75 kHz broadband system, RDI, which profiled at 8-meter vertical resolution and vector-averaged the 2-second ping data onto a 5-minute time series with vertical range of sampling from 20 to 660 m depth, approximately. It did reach down to 300 m to 500 m depth. The measurement system included ship's GPS receiver and gyrocompass. The ship position was corrected by using the differential signal from the land when it was received. The alignment misfit between gyrocompass and ADCP, and the scale factor of ADCP were estimated and corrected by using the bottom tracking data obtained in this cruise.

Personnel

Yasushi YOSHIKAWA (JAMSTEC)	Principal Investigator
Shoichiro SUEYOSHI (GODI)	Operation Leader

Objective

Objective is to study the flow fields both hydrographic sections of WHP-P17C and -P17N, and the North Pacific along the ship track.

Instruments and data acquirement system

The ADCP mounted on the R/V Mirai was 75 kHz broadband system, RDI-VM75. We set the parameters of each ADCP profile as 8 m vertical resolution with vertical range of sampling from 20 to 660 m depth, approximately. The ship's ADCP did reach down to 300 m to 500 m depth. The 2 seconds ping data were averaged onto a 5 minutes time series. The ADCP observation was carried underway in this cruise from Sekinehama to Dutch Harbor.

A single GPS receiver was used for ship's positioning. It was calibrated by using differential signal sounded from Sapporo, Honolulu, and Vancouver when the signal was received. From the signal from Vancouver was almost covered in this hydrographic section P17C and P17N.

Ship's gyrocompass was used for the measurement of the ADCP direction. The gyrocompass correlated its error factors, so-called 'the velocity error' and 'the latitude error', automatically. There were no system that measured ship's pitch and roll. There existed unknown alignment misfit. The scale factor for the ADCP velocity was also to be estimated. Therefore we took special ship course in this cruise for the estimations.

Estimations of the alignment misfit and the scale factor

In order to estimate the alignment misfit and the scale factor four special ship tracks were arranged; three round-trip courses and two bottom-tracking courses were set up. Among them we used the first bottom tracking data for the estimation because the stable data were collected. Bottom speed data those were sampled every 4 seconds, were averaged onto a 2 minutes time series. The alignment misfit ϕ and the scale factor A are estimated by using following formula shown in Joyce (1989) and Pollard and Read (1989),

$$\tan\phi = (v'_d u_s - u'_d v_s) / (u'_d u_s + v'_d v_s),$$

$$A = \text{square root } ((u_s^2 + v_s^2) / (u'^2_d + v'^2_d)),$$

where, u_s and v_s are east-west and north-south components of the ship speed, and u'_d and v'_d are those bottom speed relative to the ship, respectively. The A and ϕ were calculated in each sample.

The scale factor A was estimated by averaging the data of the track. The mean is 0.9705 with the standard deviation of 0.0011, which corresponds to the error of 0.9 cm/s when the ship speed is 16kt. It is satisfied with the range of the result of another bottom track; the mean is 0.9699 with the standard deviation of 0.0125. The gyrocompass shows the unstable error after the ship heading changing. The time needed for becoming the stable status after the turning back was estimated as 80 minutes. By using the suitable samples the alignment misfit was estimated as –1.34 degree with the standard deviation of 0.07 degree.

Preliminary results

The ADCP velocity vectors along the cruise track were shown in Figure 1. For the sections of P17C and P17N the data when the ship stopped for the CTD operation were used for the velocity calculation. In the crossing the western north Pacific, strong flow pattern (associated with the Kuroshio and/or eddies?) was observed. In the hydrographic section, the ADCP observed the southwestward strong flow of the Alaskan Current in the sea north of 54 N (Figure 2). The flow over 20 cm/s was spreading down to 300m to 500m in this area. The core of the current existed near STN.96, where the current speed was over 50 cm/s at the 50 m depth.

Data archives

The raw data will be submitted to the Data Management Office (DMO) in JAMSTEC.

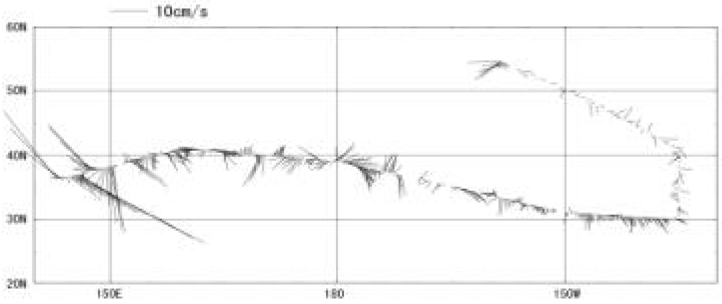

Figure 1: ADCP velocity vectors along the cruise track for 100 m depth.

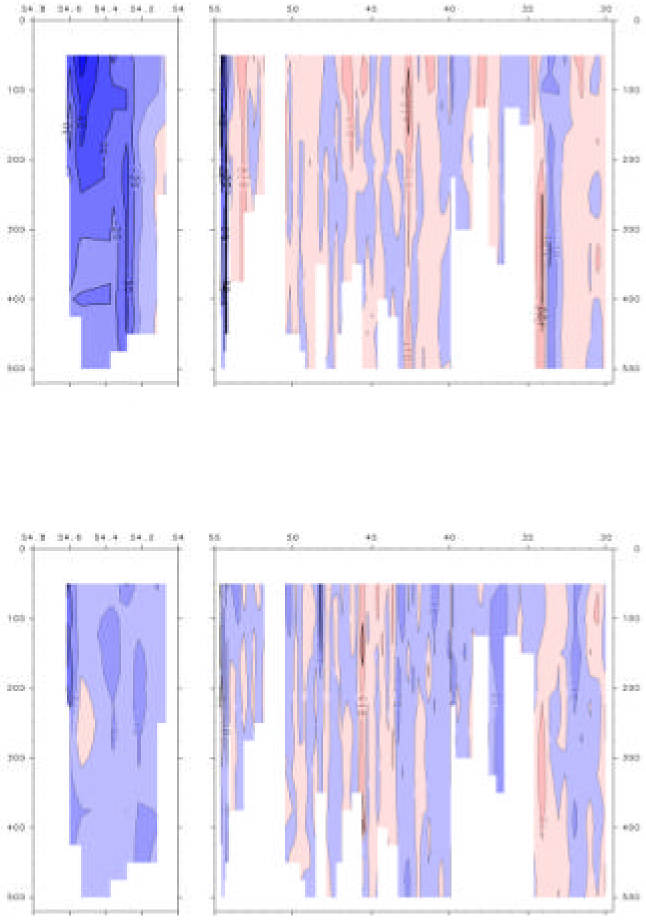

Figure 2: ADCP velocity pattern (cm/s) at sections of P17C and P17N, upper-panel) u-component, lower-panel) v-component. Northern part of the right panel is zoomed in on the left panel.

2.3 Surface Nutrients

Personnel

Junko Hamanaka (MWJ): Operation Leader
Kenichiro Sato (MWJ)
Asako Kubo (MWJ)

Scientific background

Phytoplankton require nutrient elements for growth, chiefly nitrogen, phosphorus, and silicon. The data of nutrients in surface seawater is important for investigation of phytoplankton productivity.

Parameters

- Nitrate+ Nitrite
- Nitrite
- Phosphate
- Silicate

Methods

The nutrients monitoring system was performed on BRAN+LUEBBE continuous monitoring system Model TRAACS 800 (4 channels) from July 24 to August 10, 2001. This system was located at the surface seawater laboratory for monitoring in R/V Mirai. Seawater at depth of 4.5 m was continuously pumped up to the laboratory and introduced direct to monitoring system with narrow tube. The methods are as follows.

Nitrate + Nitrite: Nitrate in the seawater was reduced to nitrite by reduction tube (Cd-Cu tube), and the nitrite reduced was determined by the nitrite method as shown below. The flow cell was 3 cm length type.

Nitrite: Nitrite was determined by diazotizing with sulfanilamide by coupling with N-1-naphthyl-ethylendiamine (NED) to form a colored azo compound, and by being measured the absorbance of 550 nm using 3 cm length flow cell in the system.

Phosphate: Phosphate was determined by complexing with molybdate, by reducing with ascorbic acid to form a colored complex, and by being measured the absorbance of 800 nm using 5 cm length flow cell in the system.

Silicate: Silicate was determined by complexing with molybdate, by reducing with ascorbic acid to form a colored complex, and by being measured the absorbance of 800 nm using 3 cm length flow cell in the system.

Data sharing

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

2.4 Atmospheric and surface seawater $P(CO_2)$

Personnel

A. Murata (JAMSTEC)
M. Kitada (MWJ)
M. Kamata (MWJ)
T. Kitao (KANSO)

Instrument and technique

Continuous underway measurements of atmospheric and surface seawater $P(CO_2)$ were made with the CO_2 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 CO_2 in dry air (xCO_2a), air sampled from the bow of the ship (approx. 30 m above the sea level) introduced into the NDIR through a dehydrating route with an electric dehumidifier (kept at 3 °C), a Pure dryer, and a chemical desiccant ($Mg(ClO_4)_2$). The flow rate of the air was 500 ml min^{-1}. To measure surface seawater concentrations of CO_2 in dry air (xCO_2s), the air equilibrated with seawater within the equilibrator was introduced into the NDIR through the same flow route as the dehydrated used in measuring CO_2. The seawater was taken by a pump from the intake placed at the approx. 4.5 m below the sea surface. The flow rate of seawater in the equilibrator was 500 – 800 ml min^{-1}.

The CO_2 measuring system was set to repeat the measuring cycle such as 4 kinds of CO_2 standard gases (see below), xCO_2a (twice), xCO_2s (7 times), and this system was run throughout the cruise.

Calibration and standards

Four working standard gases, with nominal values of 298, 321, 370, 440 ppmv in synthetic air, were used during the measurements on board the vessel. Prior to the cruise (Jul., 2001), the CO_2 standard gases used on the cruise were calibrated against primary standard gases, which were calibrated by Dr. C.D. Keeling of the Scripps Institution of Oceanography (SIO). The calibrated concentrations were 298.57, 321.19, 370.72 and 439.97 ppmv. After the cruise (Nov., 2001), we re-calibrated the working standard gases. The re-calibrated concentrations were 298.56, 321.15, 370.78 and 439.93 ppmv. Since the differences between before and after the cruise were all less than 0.1 ppmv, we calculated the sampled xCO_2a and xCO_2s using the averaged concentrations of 298.56, 321.17, 370.75 and 439.95 ppmv.

Data selection

The CO_2 measuring system used an analogue recorder for output voltages from the NDIRs. The analogue recorder was used to select background and significant signals of

each measured item by rejecting variant signals that resulted from contamination by the ship's ventilation air, the rolling and pitching of the ship due to rough weather, etc. In addition, plots of the values as a function of sequential time also facilitated the visual detection of abnormal values.

For xCO_2a, we used the data only when difference of two consecutive measurements (6 min. interval) was within 0.15 ppmv to obtain background values. The averages of the two measurements (336 pairs) are reported in the data file.

For xCO_2s, a measurement of 3,418 passed the data selection rule.

Calculation of $P(CO_2)$

$P(CO_2)$ was calculated based on the following equation:

$$P(CO_2) = (1 - e/P) \cdot xCO_2,$$

where e and P are saturated water vapor and air pressure, respectively. The e was calculated as a function of water temperature and salinity (Weiss and Price, 1980).

For surface seawater $P(CO_2)$, the rise in seawater temperature between the intake and the equilibrator is critical.--- in the cruise, the rise was usually less than 0.3 °C. The effects of the temperature rise were corrected using the equation of Gordon and Jones (1973).

Distributions of atmospheric and surface seawater $P(CO_2)$

Latitudinal distributions of atmospheric and surface seawater $P(CO_2)$ along the WOCE line are displayed in Figure 1. From this figure, it was found that south of 43°N, the sea acted as a source for atmospheric CO_2, while north of 43°N, it acted as a weak sink for atmospheric CO_2, or was almost saturated with atmospheric CO_2.

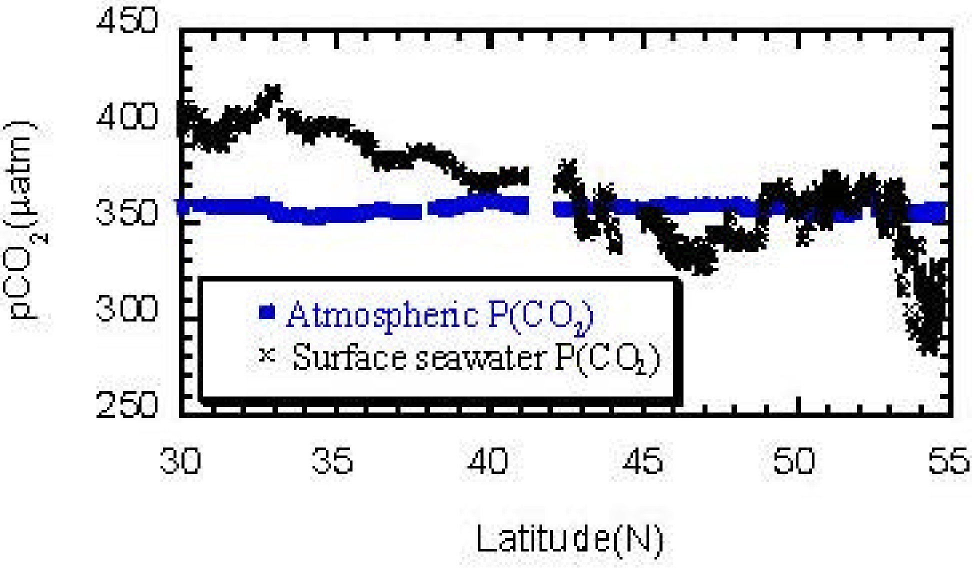

Figure 1: Distributions of atmospheric and surface seawater P(CO_2) as a function of latitude along the WOCE line.

References

Gordon. L.I. and Jones, L.B. 1973. The effect of temperature on carbon dioxide partial pressure in seawater. *Mar. Chem.* **1**, 317–322.

Weiss, R.F., and Price, B.A. 1980. Nitrous oxide solubility in water and seawater. *Mar. Chem.* **8**, 347-359.

2.5 Surface seawater total carbon (C_T)

Personnel

A. Murata (JAMSTEC)
M. Kitada(MWJ)
M. Kamata(MWJ)
T. Kitao (KANSO)

Instrument and technique

Continuous underway measurements of surface seawater C_T was made with the C_T measuring system (Nippon ANS, Ltd) installed in the R/V *Mirai* of JAMSTEC. The system comprises of a sea water dispensing system, a CO_2 extraction system and a coulometer (Model 5012, UIC Inc.).

The sea water dispensing system has an auto-sampler which collects sea water in a 300 ml borosilicate glass bottle, and dispenses the sea water to a pipette of nominal 30 ml volume by PC control. The sea water taken at approx. 4.5 m depth was introduced to the glass bottle by a pump of the *Mirai*. Time and position of sea water sampling were recorded automatically through a ship's navigation system, together with water temperature and salinity, which were measured by a Continuous Sea Surface Water Monitoring System (Nippon Kaiyo, Ltd) of the *Mirai*.

CO_2 dissolved in a sea water sample was extracted in a stripping chamber of the CO_2 extraction system by adding phosphoric acid (10 % v/v). The stripping chamber is made approx. 25 cm long and has a fine frit at the bottom. To degass CO_2 as quickly as possible, heating wire kept at 40 °C is rolled from the bottom to a 1/3 height of the stripping chamber. The acid was added to the stripping chamber from the bottom of the chamber by pressurizing an acid bottle for a given time to push out the right amount of acid. The pressurizing was made with nitrogen gas (99.9999 %). After the acid was transferred to the stripping chamber, sea water samples collected in a pipette were introduced to the stripping chamber by the same method as in adding an acid. The sea water reacted with phosphoric acid was stripped of CO_2 by bubbling the nigrogen gas through a fine frit at the bottom of the stripping chamber. The CO_2 stripped in the chamber was carried by the nitrogen gas (flow rate of 130 ml min^{-1}) to the coulometer through a dehydrating module. The module consists of two electric dehumidifiers (kept at 1 °C) and a chemical desiccant ($Mg(ClO_4)_2$).

The measurement sequence such as system blank (phosphoric acid blank), 2 % CO_2 gas in a nitrogen base, sea water samples (4) was programmed to repeat throughout the operation. The measurement of 2 % CO_2 gas was made to monitor response of coulometer solutions (from UIC, Inc.).

Calibration

Calibration was made using 6 Na_2CO_3 solutions of nominal 0.0, 500, 1000, 1500, 2000 and 2500 mol dm^{-3}. The slope of the linear regression equation (R^2 = 0.99998) was used as the calibration factor. Certified reference materials (CRM; Bach #53) provided by Prof. A.G. Dickson of SIO were measured when a coulometer solution was renewed. All the values reported were recalibrated against the certified value of the CRM.

Stability of the measuring system

Changes of C_T due to changes of response of a coulometer were monitored by measuring 2 % CO_2 gas periodically; coulometer counts of the 2 % CO_2 gas at respective sample measurements were interpolated from the measured coulometer counts of the gas, which were obtained at every 5 measurements. Then, based on the count assigned to each sample measurement, C_Ts were corrected so as to be measured at the coulometer response of CRM measurement.

The values of CRM measured during the operation of the system are plotted as a function of elapsed day (Figure 2).

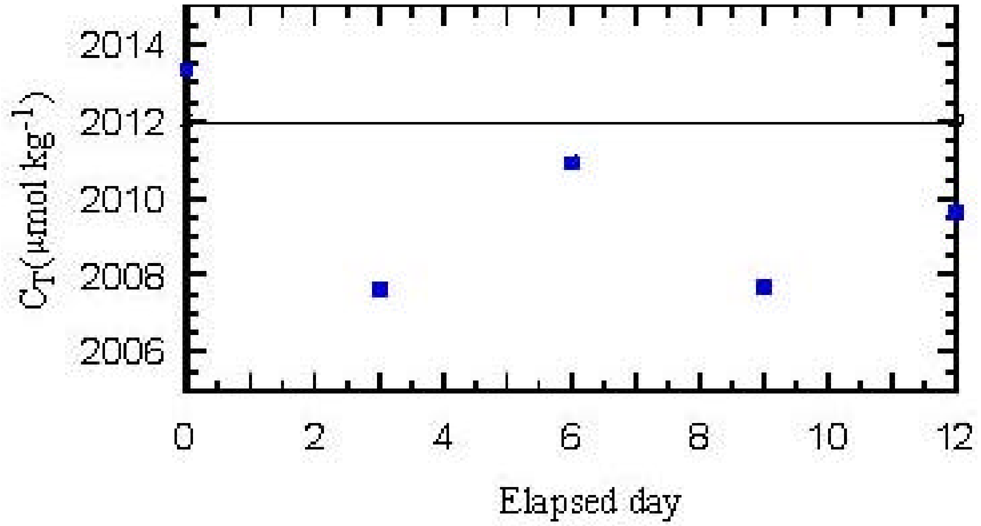

Figure 2: Plots of measured values of CRM (Bach #53) as a function of elapsed day during the cruise. The horizontal line indicates the certified value of 2012.00 µmol kg^{-1}.

Uncertainty

The CRMs were measured twice from one bottle. The number of measurement was 10 (5 pairs) in total. The average value of the two analyses was used for CRM correction. The average difference between the average of the two CRM analyses and the certified value (2012.00 mol kg^{-1}) was 2.1 ± 2.1 µmol kg^{-1}.

Distributions of surface seawater C_T

Distributions of surface seawater C_T were illustrated as a function of year day in Figure 3.

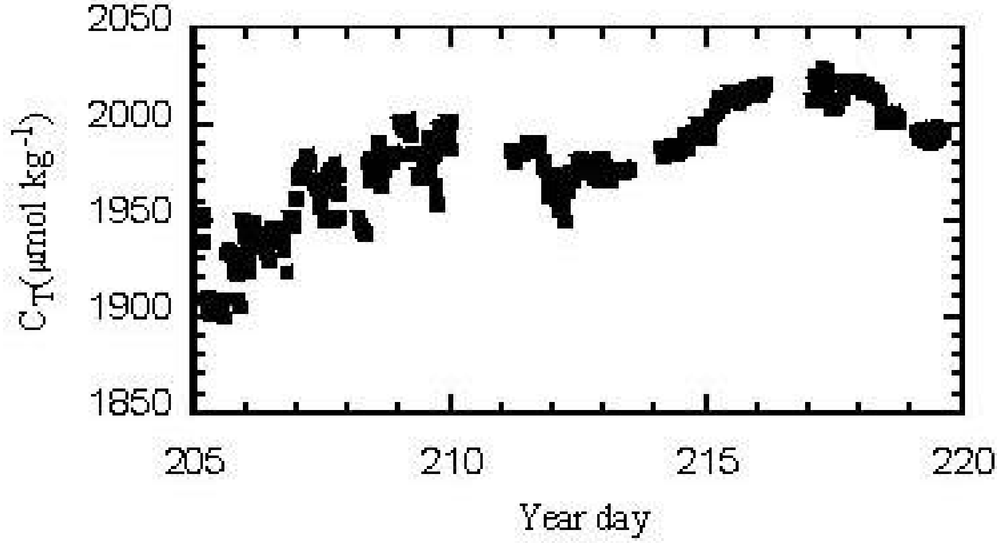

Figure 3: Distributions of surface seawater C_T as a function of year day. The year day 205 corresponds to 25 July, 2001.

2.6 Surface Nutrients

Personnel

Junko Hamanaka (MWJ): Operation Leader
Kenichiro Sato (MWJ)
Asako Kubo (MWJ)

Scientific background

Phytoplankton require nutrient elements for growth, chiefly nitrogen, phosphorus, and silicon. The data of nutrients in surface seawater is important for investigation of phytoplankton productivity.

Parameters

- Nitrate+ Nitrite
- Nitrite
- Phosphate
- Silicate

Methods

The nutrients monitoring system was performed on BRAN+LUEBBE continuous monitoring system Model TRAACS 800 (4 channels) from July 24 to August 10, 2001. This system was located at the surface seawater laboratory for monitoring in R/V Mirai. Seawater at depth of 4.5 m was continuously pumped up to the laboratory and introduced direct to monitoring system with narrow tube. The methods are as follows.

Nitrate + Nitrite: Nitrate in the seawater was reduced to nitrite by reduction tube (Cd-Cu tube), and the nitrite reduced was determined by the nitrite method as shown below. The flow cell was 3 cm length type.

Nitrite: Nitrite was determined by diazotizing with sulfanilamide by coupling with N-1-naphthyl-ethylendiamine (NED) to form a colored azo compound, and by being measured the absorbance of 550 nm using 3 cm length flow cell in the system.

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Silicate: Silicate was determined by complexing with molybdate, by reducing with ascorbic acid to form a colored complex, and by being measured the absorbance of 800 nm using 3 cm length flow cell in the system.

Data sharing

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

2.7 Surface T, S, DO

Personnel

Tomoko MIYASHITA (MWJ)
Katsunori SAGISHIMA (MWJ)
Yuichi SONOYAMA (MWJ)

Objective

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

Methods

The *Continuous Sea Surface Water Monitoring System* (Nippon Kaiyo co.,Ltd.) has six kind of sensors and can automatically measure salinity, temperature, dissolved oxygen, fluorescence and particle size of plankton in near-sea surface water continuously, every 1-minute. This system is located in the "*sea surface monitoring laboratory*" on R/V Mirai. This system is connected to shipboard LAN-system. Measured data is stored in a hard disk of PC every 1-minute together with time and position of 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 was 12L/min except with fluorometer (about 0.3L/min). The flow rate is measured with two flow meters and each values were checked everyday.

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

a) Temperature and Salinity sensor

SEACAT THERMOSALINOGRAPH
Model: SBE-21, SEA-BIRD ELECTRONICS, INC.
Serial number: 2118859-2754
Measurement range: Temperature -5 to +35℃, Salinity0 to 6.5 S m-1
Accuracy: Temperature 0.01 ℃ 6month-1, Salinity0.001 S m-1 month-1
Resolution: Temperatures 0.001℃, Salinity0.0001 S m-1

b) Bottom of ship thermometer

Model: SBE 3S, SEA-BIRD ELECTRONICS, INC.
Serial number: 032607
Measurement range: -5 to +35℃
Resolution: ±0.001℃

Stability: 0.002 ℃ year-1

c) Dissolved oxygen sensor

Model: 2127, Oubisufair Laboratories Japan INC.
Serial number: 44733
Measurement range: 0 to 14 ppm
Accuracy: ±1% at 5 ℃ 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 chlorophyl a
Stability: 0.5% month-1 of full scale

e) Particle Size sensor

Model: P-05, Nippon Kaiyo LTD.
Serial number: P5024
Measurement range: 0.02681 mmt 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) during this cruise are listed below.

27-Jul.-‘01 7:06 to 26-Aug.-’01 17:48

Date sharing

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

2.8 Sea Bottom Topography Measurement

Personnel

Souichiro Sueyoshi (GODI): Operation Leader
Shinya Iwamida (GODI)

Objectives

To obtain bathymetry data contributes to geophysical investigation, and supports for CTD and sea water sampling observation.

Methods

The observation was carried out from 24 July 2001 to 26 August 2001. Bathymetry data were obtained continuously by SeaBeam2112.004 (SeaBeam, Inc., USA) 12kHz multi-narrow beam echo sounding system. In order to measure accurate depth, precise sound velocity profiles were calculated from the temperature profile of water column. During this cruise, XCTD/CTD data and SSV data were used to calculate the sound velocity profiles for most of stations.

Data archive

The dataset obtained in this cruise will be submitted to the DMO (Data Management Office), JAMSTEC and will be archived there.

3. Hydrographic Measurement Techniques and Calibrations

3.1 Sample Salinity Measurements

Personnel

Takeshi Kawano (JAMSTEC)
Takeo Matsumoto (MWJ)

Method and results

Samples were drawn into 250ml Phoenix brown glass bottles with GL45 screw caps. Bottles were reined three times with sample water before filling. Salinity was determined after sample equilibration to Lab. Temperature, at least 12 hours.

The analysis was carried out using “Guildline Autosal 8400B Salinometer”, which was modified by addition of an Ocean Scientific International peristaltic -type sample intake pump. The instrument was operated air-conditioned dedicated Lab. for “Autosal” of R/V Mirai. The room temperature was around 23 deg-C.

The bath temperature of “Autosal” was set to 24 deg-C and IAPSO Standard Seawater (SSW) Batch P139, at least one fresh vial per cast, was used to standardize the salinometer. A double conductivity ratio was defined as a median of 31 readings of the salinometer. Data collection was started after 5 seconds and it took about 10 seconds to collect 31 readings by a personal computer.

406 pairs of replicate were measured. Figure 1 shows the histgram of all the difference between replicate samples. When we consider goods measurements below 1,000m (263 pairs), the average and the standard deviation were 0.00020 and 0.00014, respectively in Practical Salinity Scale.

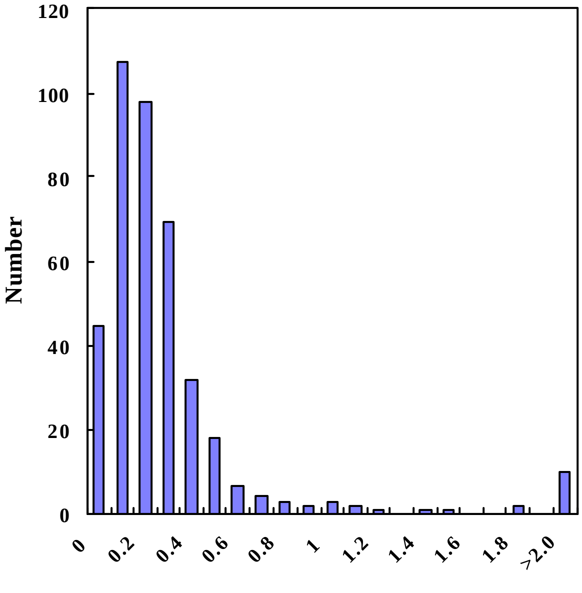

Fig.1: Histgram of the difference between reeplicates

3.2 Sample Dissolved Oxygen Measurements

Personnel

Masao Fukasawa (JAMSTEC)
Nobuharu Komai (MWJ)
Katsunori Sagishima (MWJ)

Equipment and techniques

Bottle oxygen samples were taken in calibrated clear glass bottle of 200 ml cpacity before other samples were drawn. The temperature of the water was measured at the time of the drawing for 12/36 rosette bottles to check and to allow corrections for change in density of the sample between the closure of the rosette bottle and fixing of the dissolved oxygen. As for samples of which the water temperature was not measured, potential temperature calculated from CTD results was used after a correction based on the measured temperature data. Analysis followed the whole bottle method. The thiosulfate titration was carried out in a controlled environmental laboratory maintained at temperature between 24 ded.C and 27deg.C The normality of thiosulfate was set to be 0.07 when the regents were made up, and checked their changes daily. Replicate samples were taken from six bottles (deepest bottle and DO minimum bottle are always included) on every cast.

The end point of titration was determined by an electrode method following Culberson and Huang(1987) using a Metrohm Titrator and DOSIMAT (Switzerland) auto burette with 10 ml cylinder. Titration volume were always smaller than 6 ml and the smallest increment from the burette was 1 microliters.

The volume of oxygen dissolved in the water was converted to mass fraction by use of the factor 44.66 and an appropriate value of the density; corrections for the volume of oxygen added with reagents and for impurities in the manganese chloride were also made as described in the WOCE Manual of Operation and Methods (Cilberson, 1991, WHPO 91-1).

Reproducibility of measurement

During the cruise 2420 samples were taken including 513 of replicates. Statistics on the replicates are given in Table 1. These include both replicates and those taken from different bottles fired at the same depth.

Table 1: Statistics of replicates and duplicate obtained during the cruise

Number of	Oxygen concentration umol/kg		
replicates	mean difference	Std. dev	%mean
473	0.28 $mmol/kg$	0.22 $mmol/kg$	0.19

Cross section

Figure 1 shows the cross section of bottle DO produced using data with quality flags of 2 and 3. Ocean Data View (version 5.4) by Reiner Schlitzer was hired as a graphic softwear.

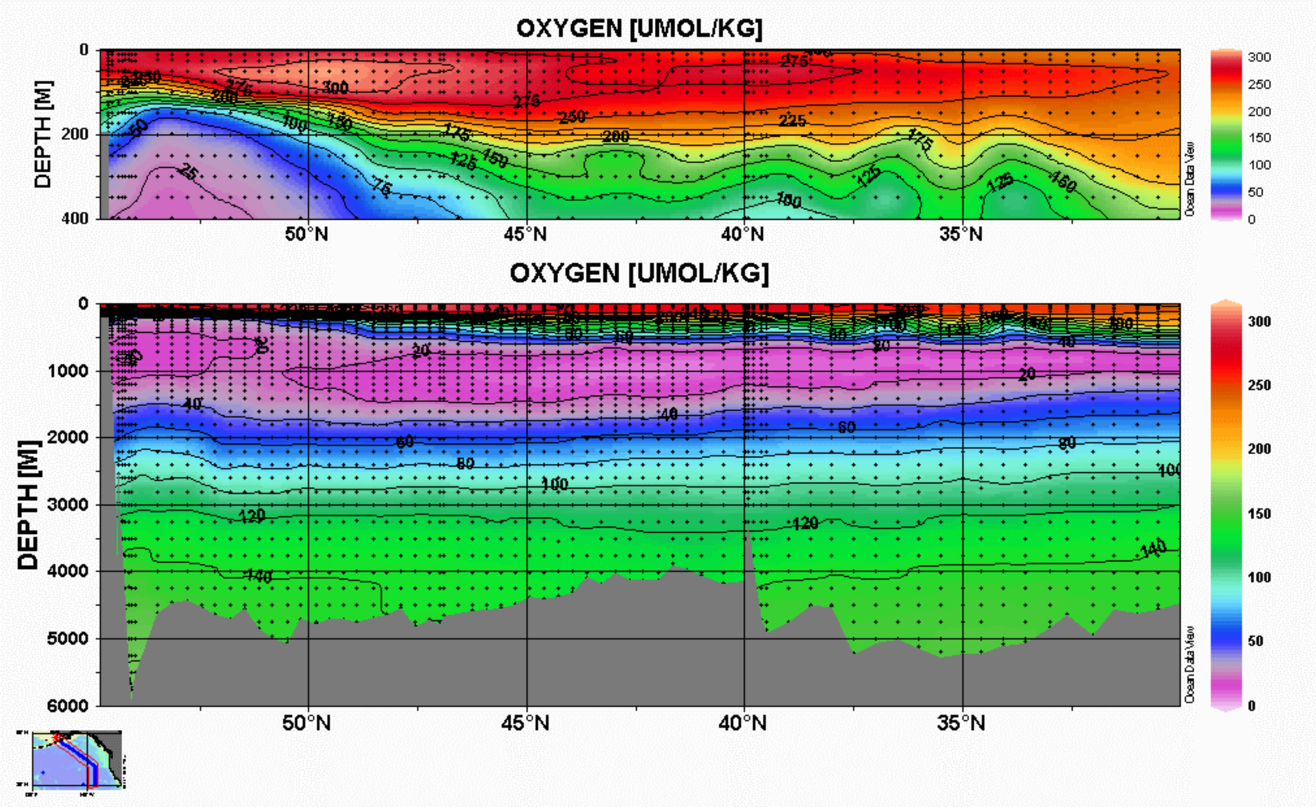

Figure 1: Cross section of bottle DO. Bad measurement data were omitted.

3.3 Total alkalinity (A_T)

Personnel

Akihiko Murata (JAMSTEC)
Fuyuki Shibata (MWJ)
Keisuke Watak (MWJ)
Taeko Ohama (MWJ)

Sample collection

All sea water samples collected from depth using 12 liter Niskin bottles at every two stations. The sea water samples for A_T were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into high-density polyethylene (PE) bottles with an inner cup. The PE bottle was filled with sea water smoothly from the bottom after rinsing it twice with a small volume of sea water. The sea water samples were kept at 4 °C in a refrigerator until analysis. A few hours before analysis, the sea water samples were kept at 25 °C in a water bath.

Instrument and technique

A sea water of approx. 100 ml was transferred into a tall beaker of 200 ml (open cell) from a PE bottle using a calibrated pipette (101.63 or 102.14 ml). The water temperature at pipetting was recorded to know transferred water volume.

Measurement of A_T was made using a titration system which comprises of a titration manager (TIM900, Radiometer) and auto-burette (ABU901, Radiometer). A combination of a pH glass electrode (pHG201, Radiometer) and a reference electrode (REF201, Radiometer) was used to monitor changes of emf by titrating a sea water sample by an acid (0.1N HCl + 0.6N NaCl). The best combination of the electrodes was selected by checking titration curves of NaCl solutions titrated by 0.01N HCl. The titration was made in a thermostat bath kept at 25 °C, and was controlled by PC with a burrette operation software (Tim Talk 9, Lab Soft).

Calculation of A_T was made based on a modified Gran approach using emfs ranging from 150 to 210 mV.

Calibration of acid titrant

Calibration of acid titrant was made by measuring A_T of 5 solutions of Na_2CO_3 in 0.7N NaCl solutions. The computed A_Ts were approx. 0, 100, 1000, 2000 and 2500 µmol kg^{-1}.

The measured values of A_T (calculated by assuming 0.1N) should be a linear function of the A_T contributed by the Na_2CO_3. The line is fitted by the method of a least square. Theoretically, the slope should be unity. If the measured slope is not equal to one, 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 is obtained.

The normality of the acid titrant used was 0.098211N.

Calibration of titrant dispensing tips

'To deliver' volumes of the auto-burette were calirbrated with pure water. Volumes of 2, 3, 4 ml delivered by the auto-burette were calibrated.

Precision and accuracy

We collected replicate samples at an interval of 5 to 8 sampling depth, approx. 5 replicate samples for each water column. The average difference of field replicate analyses was calculated to be 2.6 ± 2.6 μmol kg^{-1} (n = 181).

The CRMs (mostly Bach #54 and two Bach #53) were measured to remove biases between analyzed values of samples. The average difference between the analysed values of CRM and the certified value (2342.09 μmol kg^{-1}; Bach #45) was calculated to be 3.6 ± 3.3 μmol kg^{-1} (n = 18).

All the values reported were recalibrated against certified values of CRMs.

Comparison with the past P17 data

The A_Ts obtained by the past P17 observation are shown in Figure 1, together with the A_Ts obtained in this cruise. According to Lamb et al. (2002), 12 μmol kg^{-1} was subtracted from the values of the past P17 observation.

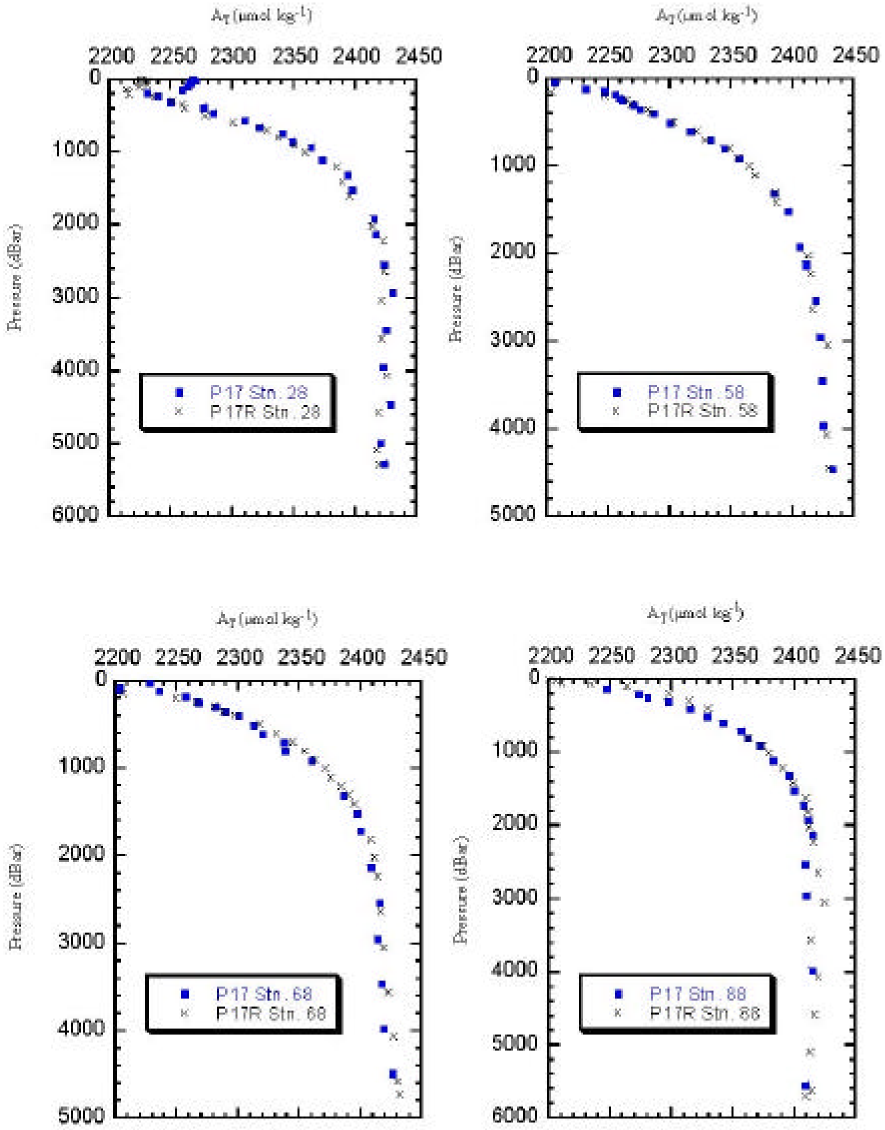

Figure 1: Vertical distributions of A_T obtained (solid squares) in the past P17 and (crosses) in this cruise.

From Figure 1, it is found that in the deep layers, A_Ts obtained in this cruise accord well with the A_Ts obtained in the past P17 cruise. However, further detailed investigations are necessary for evaluating accurate differences between the cruises.

References

Lamb, M.F., Sabine, C.L., Feely, R.A., Wanninkhof, R., Key, R.M., Johnson, G.C., Millero, F.J., Lee,,K..,Peng, T.-H., Kozy, A., Bullister, J.L., Greeley, D., Byrne, R.H., Chipman, D.W., Dickson, A.G., Goyet, C., Guenther, P.R., Ishii, M., Johnson, K.M., Keeling, C.D., Ono, T., Shitashima, K., Tilbrook, B., Takahashi, T., Wallace, D.W.R., Watanabe, Y.W., Winn, C., and Wong, C.S. 2002. Consistency and synthesis of Pacific Ocean CO_2 survey data. *Deep-Sea Res. II*, **49**, 21-58.

3.4 Total carbon (C_T)

Personnel

Akihiko Murata (JAMSTEC)
Mikio Kitada (MWJ)
Minoru Kamata (MWJ)
Takashi Kitao (MWJ)

Sample collection

All sea water samples collected from depth using 12 liter Niskin bottles at every two stations. The sea water samples for C_T were taken with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) into 300 ml borosilicate glass bottles. The glass bottle was filled with sea water smoothly from the bottom following a rinse with a sea water of 2 full, bottle volumes. A head-space of approx. 1 % of the bottle volume was left by removing sea water using a plastic pipette. A saturated mercuric chloride of 50 µl (later changed to 100 µl) was added to poison the sea water samples. The glass bottles were sealed with a greased (Apiezon M, M&I Materials Ltd) ground glass stopper and the clips were secured. The sea water samples were kept at 4 °C in a refrigerator until analysis. A few hours before analysis, the sea water samples were kept at 20 °C in a water bath.

Instrument and technique

Measurements of C_T was made with the total CO_2 measuring system (Nippon ANS, Ltd) installed in the R/V *Mirai* of JAMSTEC. The system comprises of a sea water dispensing system, a CO_2 extraction system and a coulometer (Model 5012, UIC Inc.).

The sea water dispensing system has an auto-sampler (6 ports), which takes sea water in a 300 ml borosilicate glass bottle and dispenses the sea water to a pipette of nominal 30 ml volume by PC control. The pipette was kept at 20 °C by a water jacket, in which water from a water bath set at 20 °C was circulated.

CO_2 dissolved in a sea water sample was extracted in a stripping chamber of the CO_2 extraction system by adding phosphoric acid (10 % v/v). The stripping chamber is made approx. 25 cm long and has a fine frit at the bottom. To degass CO_2 as quickly as possible, heating wire kept at 40 °C is rolled from the bottom to a 1/3 height of the stripping chamber. The acid was added to the stripping chamber from the bottom of the chamber by pressurizing an acid bottle for a given time to push out the right amount of acid. The pressrizing was made with nitrogen gas (99.9999 %). After the acid was transferred to the stripping chamber, a sea water sample kept in a pipette was introduced to the stripping chamber by the same method as in adding an acid. The sea water reacted with phosphoric acid was stripped of CO_2 by bubbling the nigrogen gas through a fine frit at the bottom of the stripping chamber. The CO_2 stripped in the chamber was carried by the nitrogen gas (flow rate of 130 ml min^{-1}) to the coulometer through a dehydrating module. The module consists of two electric dehumidifiers (kept at 1 °C) and a chemical desiccant ($Mg(ClO_4)_2$).

The measurement sequence such as system blank (phosphoric acid blank), 2 % CO_2 gas in a nitrogen base, sea water samples (4) was programmed to repeat. The measurement of 2 % CO_2 gas was made to monitor response of coulometer solutions (from UIC, Inc.).

Calibration

Calibration was made using 6 Na_2CO_3 solutions of nominal 0.0, 500, 1000, 1500, 2000 and 2500 µmol dm^{-3}. The slope of the linear regression equation (R^2 = 1.00000) was used as the calibration factor. Certified reference materials (CRM; Bach #54) provided by Prof. A.G. Dickson of SIO were measured when a coulometer solution was renewed. For a renewed coulometer solution, samples of two stations (approx. 80 samples) were measured. Reference materials (RM) produced by KANSO and JAMSTEC were measured subsequently to CRM and at about half a time of one coulometer span. All the values reported were recalibrated against the certified value of CRM.

Stability of the measuring system

Changes of C_T due to changes of response of a coulometer were monitored by measuring 2 % CO_2 gas periodically; coulometer counts of the 2 % CO_2 gas at respective sample measurements were interpolated from the measured coulometer counts of the gas, which were obtained at every 6 measurements. Then, based on the count assigned to each sample measurement, C_Ts were corrected so as to be measured at the coulometer response of CRM measurement.

The values of CRM measured during the operation of the system are plotted as a function of day (Figure 2). From this figure, it is found that there was a decreasing trend of measured values. We believe that this was caused by a contamination of a pipette.

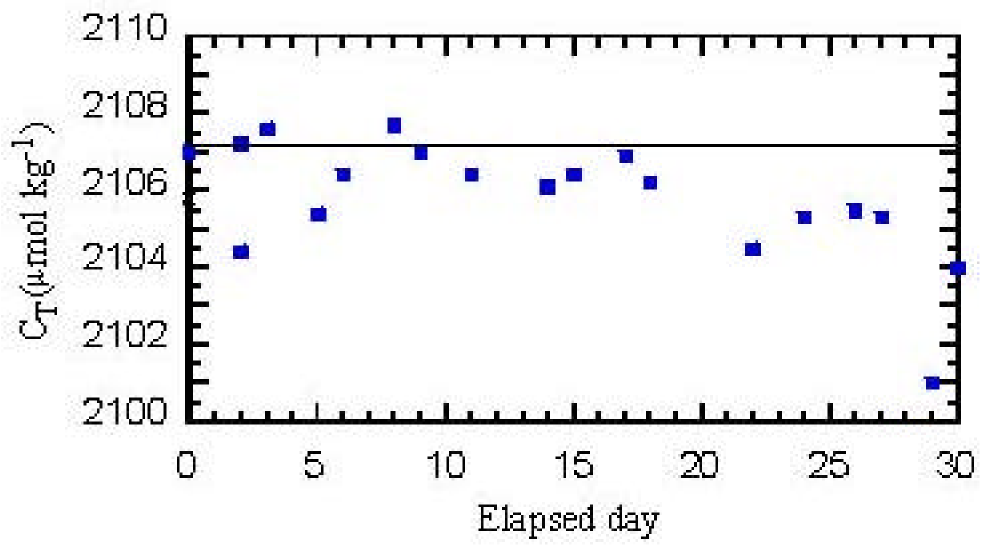

Figure 2: Plots of measured values of CRM (Bach #54) as a function of day during the cruise. The horizontal line indicates the certified value of 2107.35 μmol kg^{-1}.

Uncertainty

We collected replicate samples at an interval of 5 to 8 sampling depth, approx. 5 replicate samples for each water column. The average difference of field replicate analyses was calculated to be 1.5 ± 1.4 μmol kg^{-1} (n = 183).

The CRMs were measured twice from one bottle. The number of measurement was 38 (19 pairs) in total. The average value of the two analyses was used for CRM correction. The average difference between the average of the two CRM analyses and the certified value (2107.35 μmol kg^{-1}) was 1.5 ± 1.5 μmol kg^{-1}.

Comparison with the past P17 data

The C_Ts obtained by the past P17 observation are shown in Figure 3, together with the C_Ts obtained in this cruise. 7 μmol kg^{-1} was subtracted from the values of the past P17 observation, according to Lamb et al. (2002). From the figures, it is found that in the deep

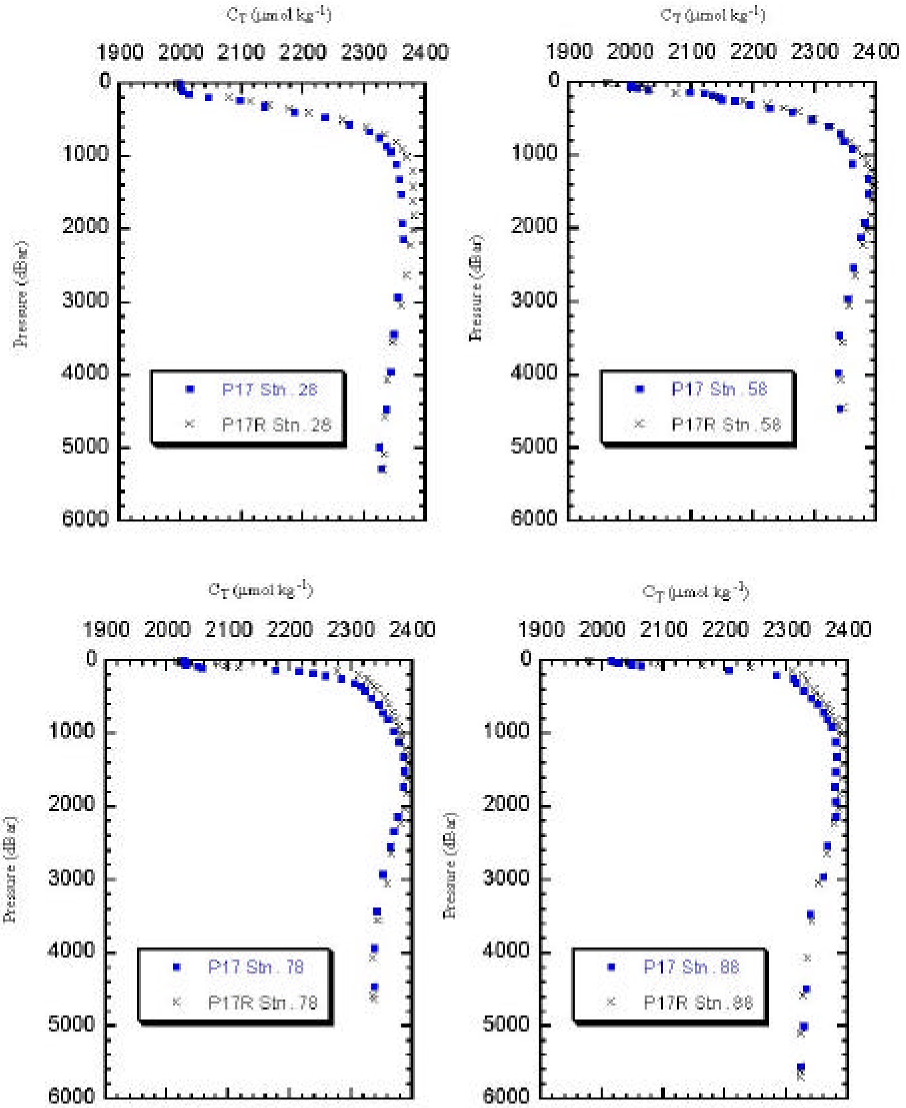

Figure 3: Vertical distributions of C_T obtained (solid squares) in the past P17 and (crosses) in this cruise.

layers, C_Ts obtained in this cruise accord well with the C_Ts obtained in the past P17 cruise. However, further detailed investigations are necessary for evaluating accurate differences between the cruises.

References

Lamb, M.F., Sabine, C.L., Feely, R.A., Wanninkhof, R., Key, R.M., Johnson, G.C., Millero, F.J., Lee, K., Peng, T.-H., Kozy, A., Bullister, J.L., Greeley, D., Byrne, R.H., Chipman, D.W., Dickson, A.G., Goyet, C., Guenther, P.R., Ishii, M., Johnson, K.M., Keeling, C.D., Ono, T., Shitashima, K., Tilbrook, B., Takahashi, T., Wallace, D.W.R., Watanabe, Y.W., Winn, C., and Wong, C.S. 2002. Consistency and synthesis of Pacific Ocean CO_2 survey data. *Deep-Sea Res. II*, **49**, 21-58.

3.5 pH

Personnel

Andray Andreev (JAMSTEC)
Akihiko Murata (JAMSTEC)
Taeko Ohama (JAMSTEC)

Sample collection

All seawater samples collected from depth using 12 liter Niskin bottles at every two stations. The seawater samples for pH were taken with a plastic drawing tube (PEA tubing connected to silicone rubber tubing) into high-density polyethylene (PE) bottles with an inner cup. The PE bottle was filled with seawater smoothly from the bottom after rinsing it twice with a small volume of seawater. Special care was given to allow no air space in the samples. The sea water samples were kept at 4℃ in a refrigerator until measurement. A few hours before measurement, the seawater samples were kept at 25℃ in a water bath.

Instrument and technique

Separate glass (Radiometer PHG201) and reference (Radiometer REF201) electrodes were used. The e.m.f. of the glass / reference electrode cell was measured with a pH / Ion meter (Radiometer PHM95). In order not to have seawater sample exchange CO_2 with the atmosphere during pH measurement, closed glass container with water jacket was used. The temperature during pH measurement was monitored with temperature sensor (Radiometer T901) and controlled at 25℃ within ±0.1℃.

Calibration

To calibrate the electrodes the TRIS (pH=8.0936 pH unit at 25℃; Delvalls and Dickson, 1998) and AMP (pH=6.786 pH unit at 25℃; DOE, 1994) in the synthetic seawater (S=35 PSU) (total hydrogen scale) were applied.

pH_T of seawater sample (pH_{samp}) is calculated from the expression:

$$pH_{samp} = pH_{TRIS} + (E_{TRIS} - E_{samp}) / ER$$

where electrode response, ER, is calculated as fllows:

$$ER = (E_{AMP} - E_{TRIS}) / (pH_{TRIS} - pH_{AMP})$$

ER value should be equal to the ideal Nernst value as follows:

$$ER = RT\,LN(10) / F = 59.16\ \text{mV} / \text{pH unit at } 25^{\circ}\text{C}.$$

Precision and accuracy

At each station, 4 to 6 duplicate samples were measured, 180 pairs in total. The average difference was calculated to be 0.003 ± 0.003 pH unit.

References

DelValls, T.A., and Dickson, A.G. 1998. The pH of buffers based on 2-amino-2-hydroxymethyl-1,3-propanediol ("tris") in synthetic seawater. *Deep-Sea Res.*, **45**, 1541-1554.

DOE. 1994. In: Dickson, A.G., and Goyet, C. (Eds.), Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea Water, version 2, ORNL/CDIAC-74.

3.6 CFCs

Personnel

Shuichi Watanabe (JAMSTEC)
Akihiko Murata (JAMSTEC)

Sample collection

All sea water samples were collected from depth using 12 liter Niskin bottles at every two stations. Duplicate sea water samples were taken from each Niskin bottle following sampling for oxygen. The sea water samples were transferred with a plastic drawing tube (PFA tubing connected to silicone rubber tubing) to glass ampoules of a volume of approx. 100 ml. The ampoule was filled with sea water smoothly from the bottom following a rinse with a sea water of 2 full, ampoule volumes. To prevent the samples from contamination from ambient air, the mouths of the ampoules were covered with a small glass container immediately after sampling. The ampoules were flame-sealed under nitrogen (99.9999 %) flow.

3.7 Carbon Isotope Ratios in dissolved inorganic carbon ($\delta^{13}C$ and $\Delta^{14}C$)

Personnel

Yuichiro Kumamoto (JAMSTEC)

Sample collection

The sampling stations and number of samples are summarized in Table 1. All samples for carbon isotope ratios were collected from depth using 12 liter Niskin bottles. The seawater sample was siphoned into a 250 ml glass bottle with enough seawater to fill the glass bottle 2 times. Immediately after sampling, 5 ml of seawater was removed from the bottle and poisoned by 50 µl of saturated $HgCl_2$ solution. Then the bottle was sealed by a glass stopper with Apiezon M grease and stored in a cool and dark space on board. The sampling procedure on board basically follows the method in WOCE Operation Manual (McNichol and Jones, 1991).

Table 1: The sampling stations and number of samples for carbon isotope ratios.

Station	No. samples	No. replicate samples	Max. sampling pressure
P1726	34	3	4549
P1724	31	0	4705
P1720	33	3	4906
P1728	60	30	5288
P1730	29	0	5305
P1734	33	3	5309
P1738	30	0	4963
P1743	37	3	3742
P1746	32	0	4113
P1748	34	3	3949
P1752	32	0	4065
P1756	34	3	4445
P1758	31	0	4457
P1764	34	3	4742
P1768	31	0	4730
P1770	34	3	4846
P1774	31	0	4800
P1778	34	3	4635
P1782	31	0	4522
P1786	32	3	5620
P1794	35	0	2567
Total	712	60	

Equipment and technique for sample preparation

In our laboratory, dissolved inorganic carbon in the seawater samples were stripped cryogenically and split into three aliquots: Accelerator Mass Spectrometry (AMS) ^{14}C measurement (about 200 µmol), ^{13}C measurement (about 100 µmol), and archive (about 200 µmol). The extracted CO_2 gas for ^{14}C was then converted to graphite catalytically on iron powder with pure hydrogen gas. Details of these preparation procedures using an automated preparation system are described by Kumamoto *et al*. (2000). About a half of the sample preparations have been finished by the end of January 2002 (All the sample preparation will be finished by June 2002).

Sample measurements

d^{13}C:

The ^{13}C / ^{12}C ratio of the extracted CO_2 gas (R_{sample}) was measured using Finnigan MAT252 mass spectrometer. The ratio of R_{sample} against the ^{13}C / ^{12}C ratio of the standard ($R_{standard}$) is expressed as δ^{13}C and calculated by the following equation:

$$\delta^{13}\text{C (‰)} = (R_{sample} / R_{standard} - 1) \times 1000. \qquad (1)$$

Because the value of $R_{standard}$ was validated with NIST RM8544 (NBS19), the measured δ^{13}C is the value against the VPDB standard. About a half of the δ^{13}C measurements have been finished by the end of January 2002 (All the measurements will be finished by June 2002). The errors of the individual measurements were less than 0.01 ‰. However, reproducibility that estimated by ten replicate measurements of quality control (QC) seawaters was 0.05 ‰ (standard deviation), in which the errors of the stripping and the isotopic analysis were included.

D ^{14}C:

The ^{14}C in the graphite sample was measured by AMS facilities at National Institute for Environmental Studies in Tsukuba, Japan (Kume *et al.*1997) and Institute of Accelerator Analysis Ltd in Shirakawa, Japan. The ^{14}C results are reported as Δ^{14}C. The equation for Δ^{14}C is:

$$\Delta^{14}\text{C (‰)} = \delta^{14}\text{C} - 2\,(\delta^{13}\text{C} + 25)\,(1 + \delta^{14}\text{C} / 1000), \qquad (2)$$

where

$$\delta^{14}\text{C (‰)} = (R_{sample} / R_{standard} - 1) \times 1000, \qquad (3)$$

where R_{sample} and $R_{standard}$ denote, respectively, ^{14}C / ^{12}C ratios of the seawater sample and the NIST oxalic acid standard (HOxII) with corrections for isotopic fractionation and age correction to A.D. 1950 (Stuiver and Polach, 1977; Stuiver, 1983). About two hundreds of the Δ^{14}C measurements have been finished by the end of January 2002 (All the measurements will be finished by September 2002). Reproducibility that estimated by four replicate measurements of the QC seawaters was 3.3 ‰ (standard deviation), in which the error of the stripping, the reduction of CO_2, and the AMS analysis were included.

Preliminary results

In Figure 1, preliminary results of δ^{13}C at stations p1720- p1746 and Δ^{14}C at stations p1720- p1730 are shown. These measurements have not been assigned the WHPO quality control flags yet.

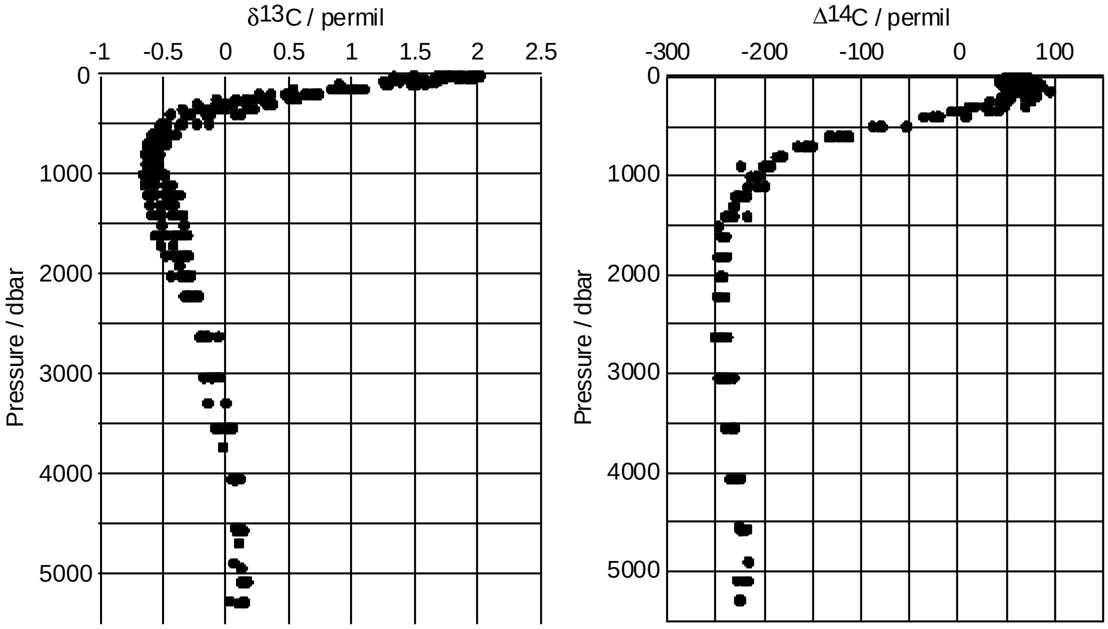

Figure 1: Preliminary results of δ^{13}C at stations P1720- P1746 (left) and Δ^{14}C at stations P1720-P1730 (right).

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Kume, H., Y. Shibata, A. Tanaka, M. Yoneda, Y. Kumamoto, T. Uehiro, and M. Morita, 1997. AMS facility at National Institute for Environmental Studies, *Nuclear Instruments and Methods in Physics Research* B123, 31-33.

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Stuiver, M. and H.A. Polach, 1977. Reporting of ^{14}C data. *Radiocarbon* 19, 355-363.

3.7 CTD/O2 Measurements

Personnel

Hiroshi Uchida (JAMSTEC)
Masao Fukasawa (JAMSTEC)
Satoshi Ozawa (MWJ)

Winch arrangements

The CTD package wad deployed using 4.5 Ton Traction Winch System (Dynacon, Inc., USA) which was installed to 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 resulted from loads variation caused by wave or vessel motion. The system is operated passively by providing a nodding boom crane that moves up or down in response to line tension variations. Primary system components include a complete CTD Traction Winch System with 10 km of 9.5 mm armored cable rocker and Electro-Hydraulic Power Unit, nodding-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.

Overview of the equipment

The CTD system, SBE911plus 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 the underwater unit, decodes the serial data stream, formats the 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 34560 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 911pus system acquires data from primary, secondary and auxiliary sensors in the form of binary numbers corresponding to the frequency or voltage outputs from those sensors at 24 samples per second. The calculations required to convert from 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 the 36-position SBE 32 Carousel Water Sampler. The Carousel accepts 12-litter water sample bottles. Bottles ware fired through the RS-232C modem connector on the back of the SBE 11plus deck unit while acquiring real time data. The 12-litter Niskin-X water sample bottle (General Oceanics, Inc., USA) is equipped with two stainless steel springs externally. The external springs are ideal for applications such as the trace metal analysis because the inside of the sampler is free from contaminants from springs.

SBE's standard temperature (SBE 3F) 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 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 (3000 rpm) remain nearly constant over the entire input voltage range of 12-18 volts DC.

The system used in this cruise is summarized as follows:

Under water unit:
SBE, Inc., SBE 9plus, S/N 79492
Temperature sensor (primary):
SBE, Inc., SBE 3-04/F, S/N 031464
Temperature sensor (secondary):
SBE, Inc., SBE 3-04/F, S/N 031524
Conductivity sensor (primary):
SBE, Inc., SBE 4-04/0, S/N 041203
Conductivity sensor (secondary):
SBE, Inc., SBE 4-04/0, S/N 041206
Oxygen sensor (primary):
SBE, Inc., SBE 13-04, S/N 130540 (from station 431 to P17N 30)
SBE, Inc., SBE 43, S/N 430069 (from station P17N 31 to P17N 99)
Oxygen sensor (secondary):
SBE, Inc., SBE 43, S/N 430069 (from station 431 to P17N 30)
SBE, Inc., SBE 13-04, S/N 130540 (from station P17N 31 to P17N 99)
Pump (primary):
SBE, Inc., SBE 5T, S/N 053118
Pump (secondary):
SBE, Inc., SBE 5T, S/N 050984
Altimeter:
Benthos, Inc., 2110-2, S/N 228 (from station 431 to P17N 29, and from station P17N 31 to P17N 33)
Benthos, Inc., 2110-2, S/N 206 (station P17N 30)

Datasonics, Inc., PSA-900D, S/N 396 (from station P17N 34 to P17N 99)

Fluorometer:

Seapoint sensors, Inc., S/N 2148

Transmissometer:

WET Labs, Inc., C-Star Transmissometer, S/N CST-207RD

Deck unit:

SBE, Inc., SBE 11plus, S/N 11P8010-0308 (from station 431 to P17N 70)

SBE, Inc., SBE 11plus, S/N 11P7030-0272 (from station P17N 71 to P17N 99)

Carousel Water Sampler:

SBE, Inc., SBE 32, S/N 3221746-0278

Water sample bottle:

General Oceanics, Inc., 12-litter Niskin-X

Pre-cruise calibration

(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. in Bellevue, Washington, USA. The following coefficients were used in the SEASOFT through software module SEACON:

S/N 79492 October 27, 1999

c1 = -65706.8
c2 = -0.1758329
c3 = 2.04245e-02
d1 = 0.027146
d2 = 0.0
t1 = 29.92375
t2 = -2.63869e-04
t3 = 3.92132e-06

t4 = 1.35947e-09

t5 = 4.49704e-12

(The coefficients c1, c2, t1 and t2 were changed on December 6, 1999.)

Pressure coefficients are first formulated into

c = c1 + c2 * U + c3 * U^2

d = d1 + d2 * U

t0 = t1 + t2 * U + t3 * U^2 + t4 * U^3 + t5 * U^4

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

U (degC) = M * (12 bit pressure temperature compensation word) – B

The following coefficients were used in SEASOFT through software module SEACON:

M = 1.284934e-2

B = -8.388034

(in the underwater unit system configuration sheet dated on November 30, 1999)

Finally, pressure is computed as

P (psi) = c * [1 – (t0^2 / t^2)] * {1 – d * [1 – (t0^2 / t^2)]}

where t is pressure period (microsec). 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 calibration against a dead-weight piston gauge are performed at Marine Works Japan Ltd. in Yokosuka, Kanagawa, Japan, usually once in a year in order to monitor its time drift and the linearity. The pressure sensor drift is known to be primarily by an offset at all pressures rather than by a change of span slope. The pressure sensor hysterisis are typically 0.2 dbar. The following coefficients for the sensor drift correction were also used in SEASOFT through the software module SEACON:

S/N 79492 April 24, 2001

slope = 0.99995898

offset = 1.78677

The drift-corrected pressure is computed as

Drift-corrected pressure (dbar) = slope * (computed pressure in dbar) + offset

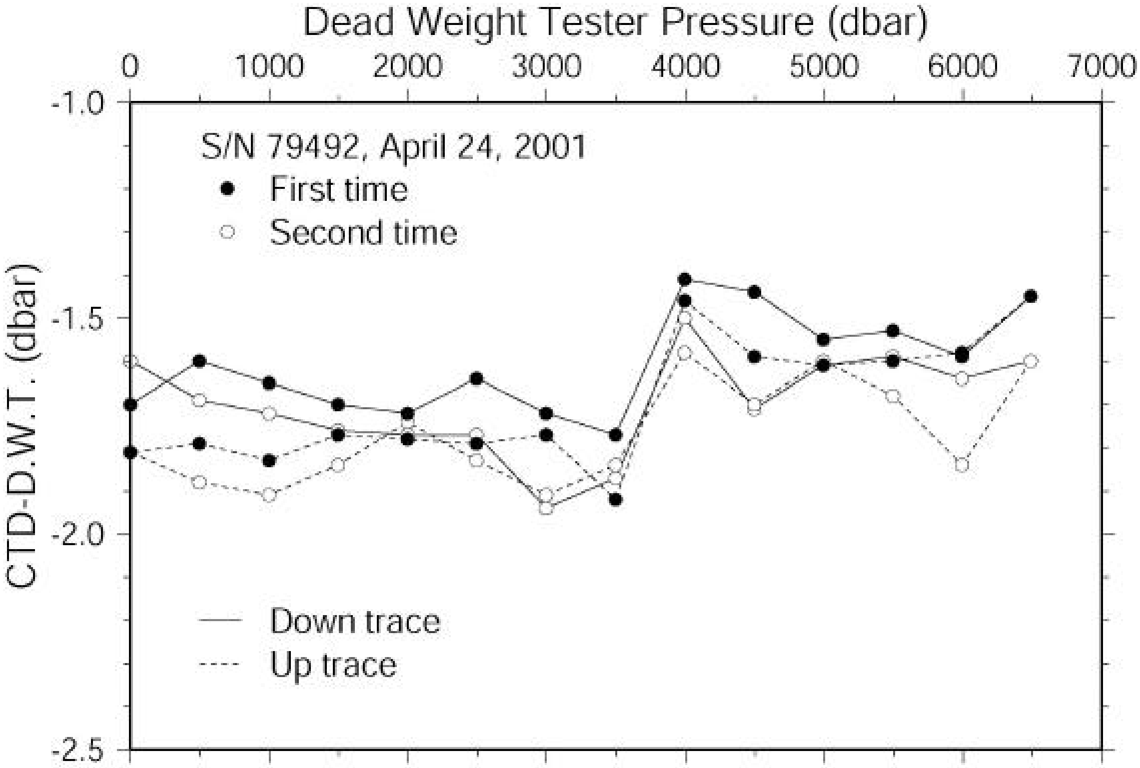

Figure 1: The residual pressures between the Dead Weight Tester and the CTD.

(2) Temperature (SBE 3F)

The temperature sensing element is a glass-coated thermistor bead in a stainless steel tube to provide a pressure-free measurement at depths up to 10,500 meters. The sensor output frequency ranges from approximately 5 to 13 kHz corresponding to temperature from –5 to 35 degC. 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 3F thermometer has a nominal accuracy of 0.001 degC, typical stability of 0.0002 degC/month and resolution of 0.0002 degC at 24 samples per second.

Pre-cruise sensor calibrations were performed at SBE, Inc. in Bellevue, Washington, USA. The following coefficients were used in SEASOFT through the software module SEACON:

S/N 031464 (primary) June 16, 2001

$g = 4.84394400e-03$
$h = 6.80848240e-04$
$i = 2.70328214e-05$
$j = 2.13867061e-06$
$f0 = 1000.000$

S/N 031524 (secondary) June 16, 2001

$g = 4.83484327e-03$
$h = 6.75462258e-04$
$i = 2.64451174e-05$
$j = 2.13440093e-06$
$f0 = 1000.000$

Temperature (ITS-90) is computed according to

$$\text{Temperature (ITS-90)} = 1 / \{g + h * [\ln(f0 / f)] + i * [\ln^2(f0 / f)] + j * [\ln^3(f0 / f)]\} - 273.15$$

where f is the instrument frequency (kHz).

(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 from 0 to 7 S/m. The conductivity cell of 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. in Bellevue, Washington, USA. The following coefficients were used in SEASOFT through the software module SEACON:

S/N 041203 (primary) June 15, 2001

g = -4.05180978
h = 4.93348008e-01
i = 9.46008409e-05
j = 2.18812300e-05
CPcor = -9.57e-08 (nominal)
CTcor = 3.25e-06 (nominal)

S/N 041206 (secondary) June 15, 2001

g = -4.28945276
h = 5.03354673e-01
i = 1.03033274e-04
j = 2.08217238e-05
CPcor = -9.57e-08 (nominal)
CTcor = 3.25e-06 (nominal)

Conductivity of a fluid in the cell is expressed as:

C (S/m) = (g + h * f^2 + i * f^3 + j * f^4) / [10 (1 + CTcor * t + CPcor * p)]

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

(4) Oxygen (SBE 13)

The SBE 13 dissolved oxygen sensor uses a Beckman polarographic element to provide in-situ measurements at depths up to 10,500 meters. The sensor is included in the path of pumped sea water. The oxygen sensor determines the dissolved oxygen concentration by counting the number of oxygen molecules per second (flux) that diffuse through a membrane. By knowing the flux of oxygen and the geometry of the diffusion path, the concentration of oxygen can be computed. The permeability of the membrane to oxygen is a function of temperature and ambient pressure. The interface electronics outputs voltages proportional to oxygen flux (oxygen current) and membrane temperature (oxygen temperature). Oxygen temperature is used for internal temperature compensation. Computation of dissolved oxygen in engineering units is done in SEASOFT software. The range for dissolved oxygen is

0 to 15 ml/l; nominal accuracy is 0.1 ml/l; resolution is 0.01 ml/l.

The following coefficients were used in SEASOFT through the software module SEACON:

S/N 130540 June 18, 2001

m = 2.4424e-07
b = -4.2986e-10
k = 8.9712
c = -6.8923
Soc = 2.2237
Boc = -0.0143
tcor = -0.033
pcor = 1.50e-04
tau = 2.0
wt = 0.67

The use of these constants in linear equations of the form I = m * V + b and T = k * V + c yield the oxygen current and the oxygen temperature (with a maximum error of about 0.5 degC), respectively. These scaled values of the oxygen current and the oxygen temperature are used in the SEASOFT processing stream.

The oxygen sensor of S/N 130540 was used with primary temperature and conductivity sensors at stations from 431 to P17N 30 and used with secondary temperature and conductivity sensors at station from P17N 31 to P17N 99.

(5) 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 hysterisis is largely eliminated in the upper ocean (1000 m). Continuous polarization eliminates the wait-time for stabilization after power-up. Signal resolution is increased by on-board temperature compensation. This Sensor is also included in the path of pumped sea water. This oxygen sensor determines the dissolved oxygen concentration also 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 through almost the same way as for the case of SBE 13. 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 1000 hours.

The following coefficients were used in SEASOFT through the software module SEACON:

S/N 430069 July 6, 2001

Soc = 0.3268
Boc = 0.0184
TCor = 0.0004
PCor = 1.500e-04
Offset = -0.6181
tau = 0

Oxygen (ml/l) is computed as

$$\text{Oxygen (ml/l)} = [Soc * \{(v + offset) + (tau * doc/dt)\} + Boc * \exp(-0.03 * t)] * \exp(TCor * t + PCor * p) * Oxsat(t, s)$$

$$Oxsat(t, s) = \exp[A1 + A2 * (100 / t) + A3 * \ln(t / 100) + A4 * (t / 100) + s * (B1 + B2 * (t / 100) + B3 * (t / 100) * (t / 100))]$$

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. Its coefficients are as follows;

A1 = -173.4292
A2 = 249.6339
A3 = 143.3483
A4 = -21.8482
B1 = -0.033096
B2 = -0.00170

The oxygen sensor of S/N 130540 was used with secondary temperature and conductivity sensors at stations from 431 to P17N 30 and used with primary temperature and conductivity sensors at station from P17N 31 to P17N 99.

(6) Altimeter

The Benthos 2110 Series Altimeter (Benthos, Inc., USA) follows the basic principal of most echo ranging devices. That is, a burst of acoustic energy is transmitted and the time until the first reflection is received is determined. In this unit, a 400 microsecond pulse at 100 kHz is transmitted twice a second; concurrent with the transmission, a clock is turned off, thus the number of pulses out relates directly to the distance of the target from the unit. The internal ranging oscillator has an accuracy of approximately 5 % and is set assuring a speed of sound of 1500 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. The unit is rated to a depth of 12,000 meters.

The Datasonics PSA-900 Programmable Sonar Altimeter (Datasonics, Inc., USA) determines the distance of the target from the unit in almost the same way as the Benthos 2110. PSA-900 also uses also uses the nominal speed of sound as 1500 m/s. But, PSA-900 compensates for sound velocity errors due to temperature. In a PSA-900 operating at a 350 microsecond pulse at 200 kHz, the jitter of the detectors can be as small as 5 microseconds or approximately 0.4 centimeters total distance. Since the total travel time is divided by two, the jitter error is 0.25 centimeters. The unit is rated to a depth of 6,000 meters.

The following scale factors were used in SEASOFT through the software module SEACON:

FSVolt * 300 / FSRange = 0.5
Offset = 0.0

(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 through the software module SEACON as user defined polynomial:

S/N 2148 (unknown calibration date)

A0 = 0.0
A1 = 5.0

Chlorophyll-a concentration is computed as

Chlorophyll-a (ug/l) = A0 + A1 * Voltage

(8) Transmissometer

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

The following coefficients were used in SEASOFT through the software module SEACON:

S/N CST-207RD March 19, 1998

M = 19.6415
B = -1.3945
Path length (m) = 0.25

The beam transmittance (Tr) iscomputed as

Tr (%) = M * voltage + B

Data Collection and Processing

(1) Data collection

CTD/O2 measurements were made using a SBE 9plus CTD equipped with two pumped temperature-conductivity (TC) sensors and dissolved oxygen sensor pair. The TC pairs ware monitored to check drift and shifts by examining the differences between the two pairs. Also a newly developed oxygen sensor (SBE 43) was compared with a Beckman type oxygen sensor (SBE 13).

The SBE 9plus CTD/O2 (sampling rate of 24 Hz) was mounted in a 36-position frame. Auxiliary sensors included altimeter, fluorometer and transmissometer. Water samples were collected using a 36-bottle SBE 32 Carousel Water Sampler with 12-litter Nisken-X bottles.

The package was lowered into the water from the board side and was held 10 m beneath the surface for about one minute in order to activate the pump. After the pump was activated the package was lowered at a rate of 0.5 m/s to 100 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 0.8 m/s to 300 m, 1.0 m/s to 500 m, and 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 multibeam sounder on the board. For the up cast, the package was heightened at a rate of 1.2 m/s except for a time when sampling water at a rate of 0.5 m/s. At 100 m deep from the surface, the package was stopped in order to stop the heave compensator of the crane.

Niskin-X bottle sampled water for analysis of salinity, dissolved oxygen, inorganic nutrients, CFCs, DIC, C-14, pH and total alkalinity. The 36-position frame and Niskin-X bottles were periodically wiped with acetone in order to prevent water samples from contamination. Niskin-X bottle's caps and O-rings were re-arranged and wiped with acetone when a bottle leaking was found.

The SBE 11plus deck unit received the data signal from the CTD. Digitized data were forwarded to a personal computer prepared for SEASAVE module of the SEASOFT acquisition and processing software of which version was 4.249. Temperature, salinity, oxygen and descent rate profiles were displayed in real-time with the package depth and altimeter reading.

(2) Data collection problems

At station P17N 29, altimeter reading was not stable and altimeter was replaced after the cast. At station P17N 30, the replaced altimeter did not work correctly and the altimeter which was removed at P17N 29 was used again. At station P17N 33, altimeter did not work and replaced with other one after the cast.

At station P17N 36, SEASAVE data acquisition software was restarted during the package was holding at 10 m depth because of incorrect setting of the software. Therefore, data shallower than 10 m were lost.

At station P17N 47, up cast CTD data was very noisy and sensor connectors were checked and cleaned after the cast. At station P17N 71, bottle #1 fired unwillfully at 900 m depth during the down cast and the first cast was aborted. On the second cast, communication error was detected at 90 m depth during the down cast and the cast was aborted. CTD cable was checked electrically and some of connectors were replaced. Also the deck unit was replaced to complete the third cast.

At station P17N 76, 78, 82, 83 and 86, the down cast was started without holding at 10 m depth because of bad weather. At station P17N 77, the package was lowered and stopped at 20 m depth because the pump did not work at 10 m depth. So the down cast was started from 20 m depth.

At station P17N 94, descent rate exceeded 3 m/s for unknown reason and the package was stopped at 326 m deep. Then the down cast was restarted checking the heave motion mechanism of the crane. A communication error was detected when the package was lowered faster than 0.8 m/s. Therefore, the package had to be lowered at slower rate than 0.8 m/s to the bottom. During the up cast, bottle #1 did not fire. Hence, the deck unit and SEASAVE data acquisition software were restarted at 100 m above bottom and the up cast restarted at the 10 m above bottom. After the cast, the end of the CTD cable was cut about 50 m. At station P17N 96, sensor error was detected at 80 m depth during the down cast and the cast was aborted. After the cast, sensor connectors were checked.

(3) Other incidents of note

Before the first CTD station of this cruise, load test of CTD cable was performed on the deck up to 4.5 ton load. At station 431, CTD package was lowered to 100 m deep before the down cast in order to regulate CTD winch system. Also on the second cast at station 431, CTD package was lowered further 70 m after firing all bottles at 3000 m deep in order to regulate CTD winch system. After the station P17N 76, the CTD cable was cut 50 m from the end and load test of CTD cable was performed on the deck up to the load of 3.3 ton. After the station P17N 94, the CTD cable was cut 23 m from the end and load test of CTD cable was performed on the deck up to the load of 4 ton.

On the fourth cast at station 431, stainless steel weight of 60 kg (10 kg * 6) were attached to the water sampler frame in order to increase the tension of the CTD cable near the surface. After the CTD cast at station P17N 40, more stainless steel weight of 60 kg (10 kg * 6) were added to the water sampler frame so that the CTD package stops rotating horizontally during down casts. But the rotation rate of the package checked from the LADCP data still to be about 0.5 revolution per minute. Therefore, at station P17N 64 and 67, the package was stopped one hour at 100 m above bottom in order to untwist the cable before the up cast.

At station P17N 69, the package was stopped 20 minutes at 100 m deep in the down cast in order to supply nitrogen gas to the Heave Compensation System. The CTD package was stopped a few minutes in order to stabilize the heave motion during down casts at station P17N 66 (1545 m), P17N 67 (350 and 1450 m), P17N 70 (1000 m), P17N 73 (1363 and 1611 m), P17N 80 (940 m), P17N 90 (723 m) and P17N 92 (1365 m).

Since the new oxygen sensor SBE 43 was recognized as a surprisingly good sensor compared to the old oxygen sensor SBE 13, the new sensor was used as primary sensor and the old sensor was used as secondary sensor after P17N 31.

CTD casts at station P17N 41 and 91 has been scheduled to be skipped. The station P17N X01 was located at the same geographical position as station 92 of WHP-P01, where CTD casts were carried out in 1985 by R/V Thomas Thompson and in 1999 by R/V Mirai and R/V J.P. Tully.

The CTD cast at station P17N 76 was delayed about 2 days than the plan because sea and weather were too severe for a CTD operation. For this reason, the station P17N 85 and 89 were canceled and the station P17N 95 and 97 were replaced with XCTD casts.

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 an IBM or 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 either rows and columns of ascii numbers. The last data column is a flag field used to mark scans as good or bad.

The following are the SEASOFT-Win32 (Ver. 5.21 or 5.23) processing module sequence and specifications used in the reduction of CTD/O2 data in this cruise. Some modules are originally developed for additional processing and post-cruise calibration.

DATCNV converted the raw data to scan number, pressure, temperatures, conductivities, oxygen current (SBE 13), oxygen temperature (SBE 13), oxygen voltage (SBE 43), chlorophyll-a concentration, transmissometer voltage and altitude. DATCNV also extracted bottle information where scans were marked with the bottle confirm bit during acquisition. The first scan was set to 2 seconds prior to the confirm bit and the duration was set to 4 seconds.

ROSSUM created a summary of the bottle data. The bottle position, date, time were output as the first two columns. Pressure, temperatures, conductivities, oxygen current (SBE 13), oxygen temperature (SBE 13), oxygen voltage (SBE 43), chlorophyll-a concentration, transmissometer voltage and altitude were averaged over 4 seconds.

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 9 CTD with the ducted temperature and conductivity sensors and a 3000 rpm pump, the typical net advance of the conductivity relative to the temperature is 0.073 seconds. So, the SBE 11plus deck unit was set to advance the primary conductivity for 1.73 scans (1.75/24 = 0.073 seconds). As the result, the secondary conductivity was advanced 0.073 seconds relative to the temperature. 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. As for the temperature and the conductivity, this delay was compensated by 5 seconds advancing oxygen sensor outputs relative to the pressure.

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 48 scans. Data greater than two standard deviations were flagged. The second pass computed a standard deviation over the same 48 scans excluding the flagged values. Values greater than 10 standard deviations were marked bad. This process was applied to pressure, temperatures, conductivities, oxygen and altimeter outputs. For oxygen voltage (SBE 43), values within displacement of 0.006 V from the mean were not marked bad. For oxygen current (SBE 13), values within displacement of 0.0015 microA from the mean were not marked bad. For oxygen temperature (SBE 13), values within displacement of 0.055 degC from the mean were not marked bad. For the data at stations of P17N 47 and P17N 71 cast 1, this process was applied twice in order to remove remaining spikes.

CELLTM used a recursive filter to remove conductivity cell thermal mass effects from the measured conductivity. Typical values were used for thermal anomaly amplitude (alpha = 0.03) and the time constant (1/beta = 9.0).

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

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

WHPHEADER (original module) added information in header record correspondingly to the WHP CTD data (EXPOCODE, WHP-ID, STNNBR, CASTNO, DATE, INSTRUMENT NO. and SAMPLING RATE).

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 a starting time when the CTD package was beneath the sea-surface after the activation of the pump. The maximum number was set to be an ending time when the package came up from the surface. (Data to check 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 only to compute the time derivative of oxygen (for the term doc/dt of SBE 13) with a time window size of 2.0 seconds.

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 exists every dbar.

DERIVE was re-used to compute salinity, depth, potential temperature, sigma-t and sigma-theta.

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

CTD/O2 Post-Cruise Calibration

(1) Pressure calibration

The CTD pressure sensor drift in the period of this 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. Only “pre-cast on deck CTD pressure” data with longer aging time than two minutes were selected and were averaged over one minute to prepare cariblation data for the pre-cast pressure sensor drift. As for the calibration data for the post-cast pressure sensor drift, the CTD deck pressure is averaged over last one minute to get a calibration data.

Then the atmospheric pressure deviation from a standard atmospheric pressure (14.7 psi) is subtracted from the CTD pressure. The atmospheric pressure was measured at the captain deck (20 m high from the base line) and averaged over one minute for a meteorological data.

The CTD pressure sensor drift is estimated from the deck pressure obtained above. An average of the pre- and the post-casts data over the whole period of this cruise gave an estimation of –0.61 dbar and the root-mean-square difference of 0.14 dbar. Since the cruise period (August 2001) was 4 months later from the pre-cruise calibration (April 2001), the typical drift was expected about 0.6 dbar. The estimated drift (0.61 dbar) is comparable to the typical drift in the specification of the present pressure sensor. Finally the CTD pressure is calibrated as

$$\text{Calibrated pressure (dbar)} = p + 0.61$$

where p is the CTD pressure in dbar.

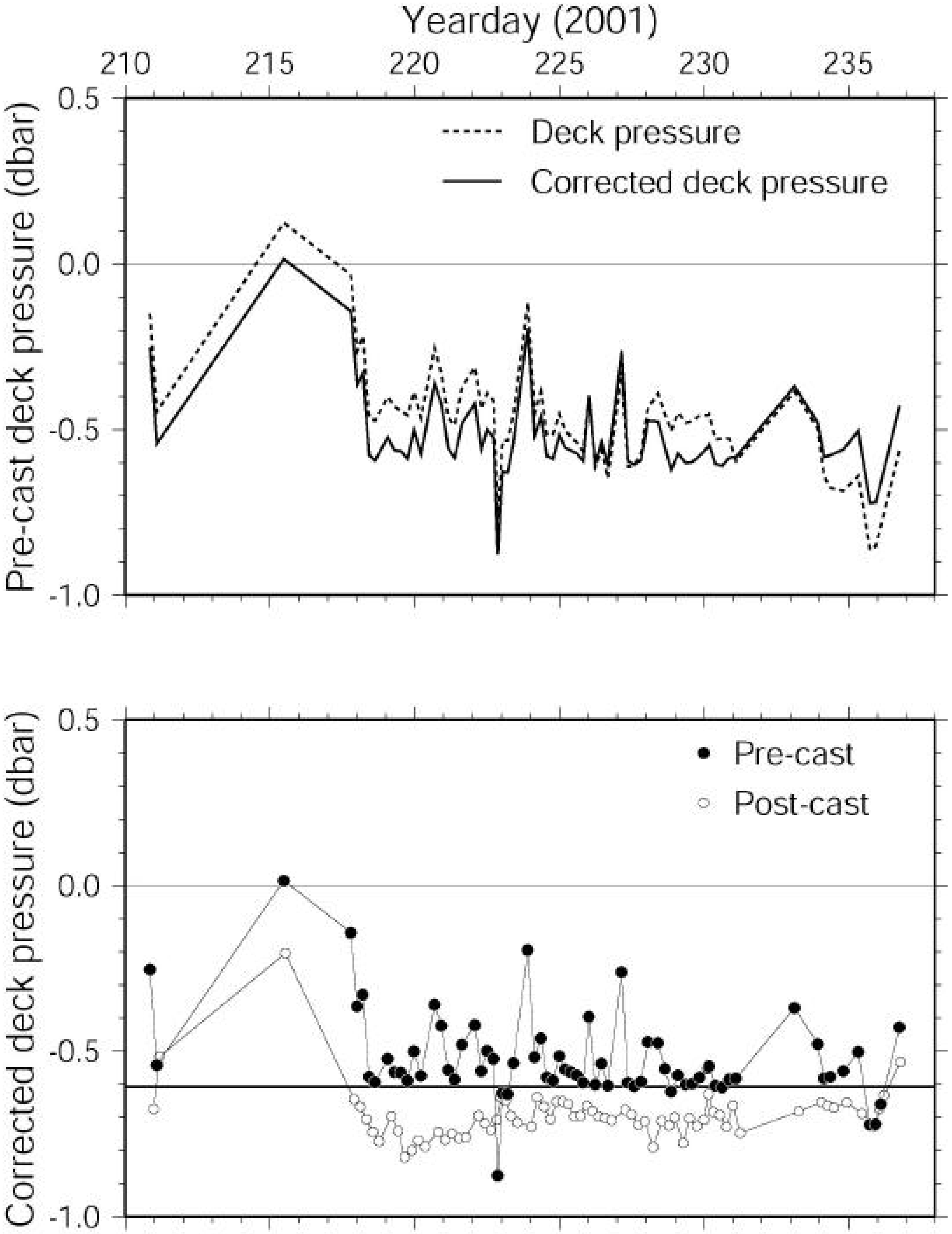

Figure 1: Time series of the CTD deck pressure. Upper panel shows the pre-cast deck pressure (dotted line) and the corrected deck pressure subtracting the atmospheric pressure deviation from the pre-cast deck pressure (solid line). Lower panel shows the corrected deck pressure for the pre- and post-cast.

(2) Temperature calibration

Post-cruise sensor calibrations were performed at SBE, Inc. in Bellevue, Washington, USA. The following coefficients were the results.

S/N 031464 September 25, 2001

g = 4.84437595e-03
h = 6.81426982e-04
i = 2.72899771e-05
j = 2.17701451e-06
f0 = 1000.000

S/N 031524 September 25, 2001

g = 4.83461183e-03
h = 6.75115071e-04
i = 2.62742100e-05
j = 2.10734809e-06
f0 = 1000.000

These temperature sensor drifts are traced since 1994 based on laboratory calibrations performed at SBE, Inc. The mean absolute residuals between the bath temperature and the CTD temperature at 11 calibration points show almost linear tendency in time for the primary temperature sensor (about 1 mdegC per year). The CTD temperature drift during each period of observation is estimated lineally using the pre- and post-cruise laboratory calibration equations. The CTD temperature calibration was carried out by subtracting the corresponding estimated drift from in-situ temperature readings.

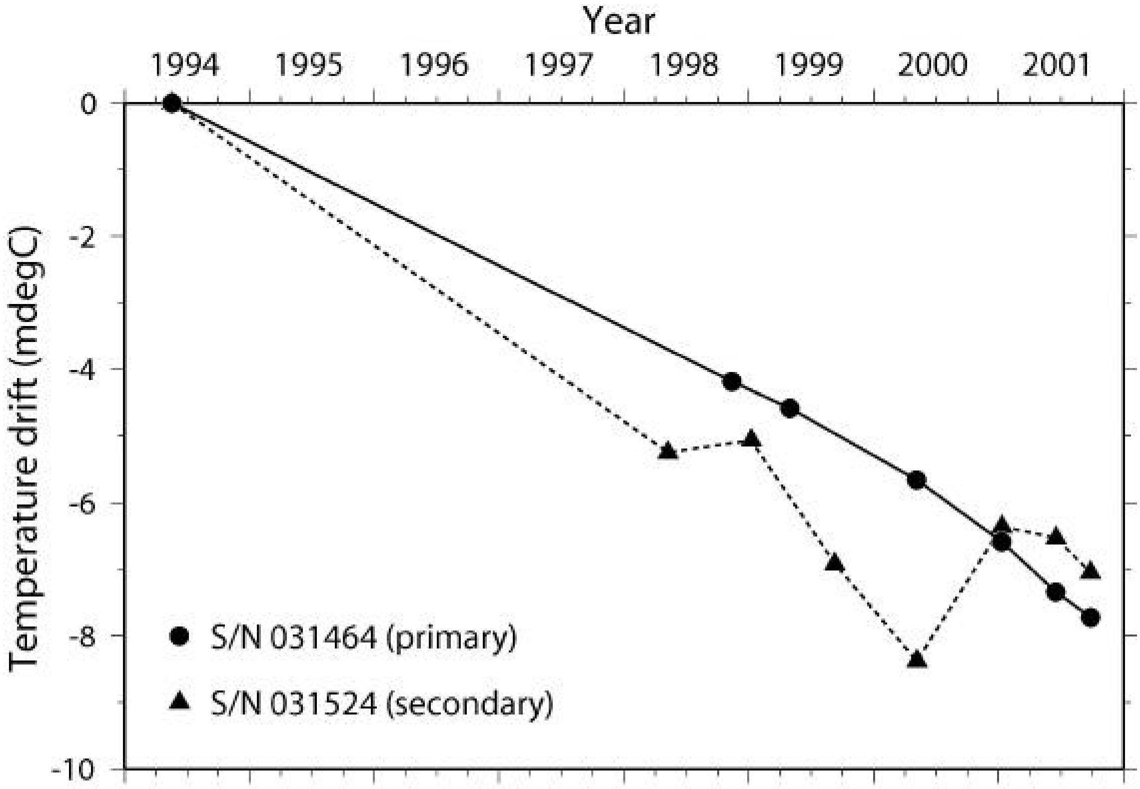

Figure 2: Temperature sensor drift based on laboratory calibrations performed at SBE, Inc.

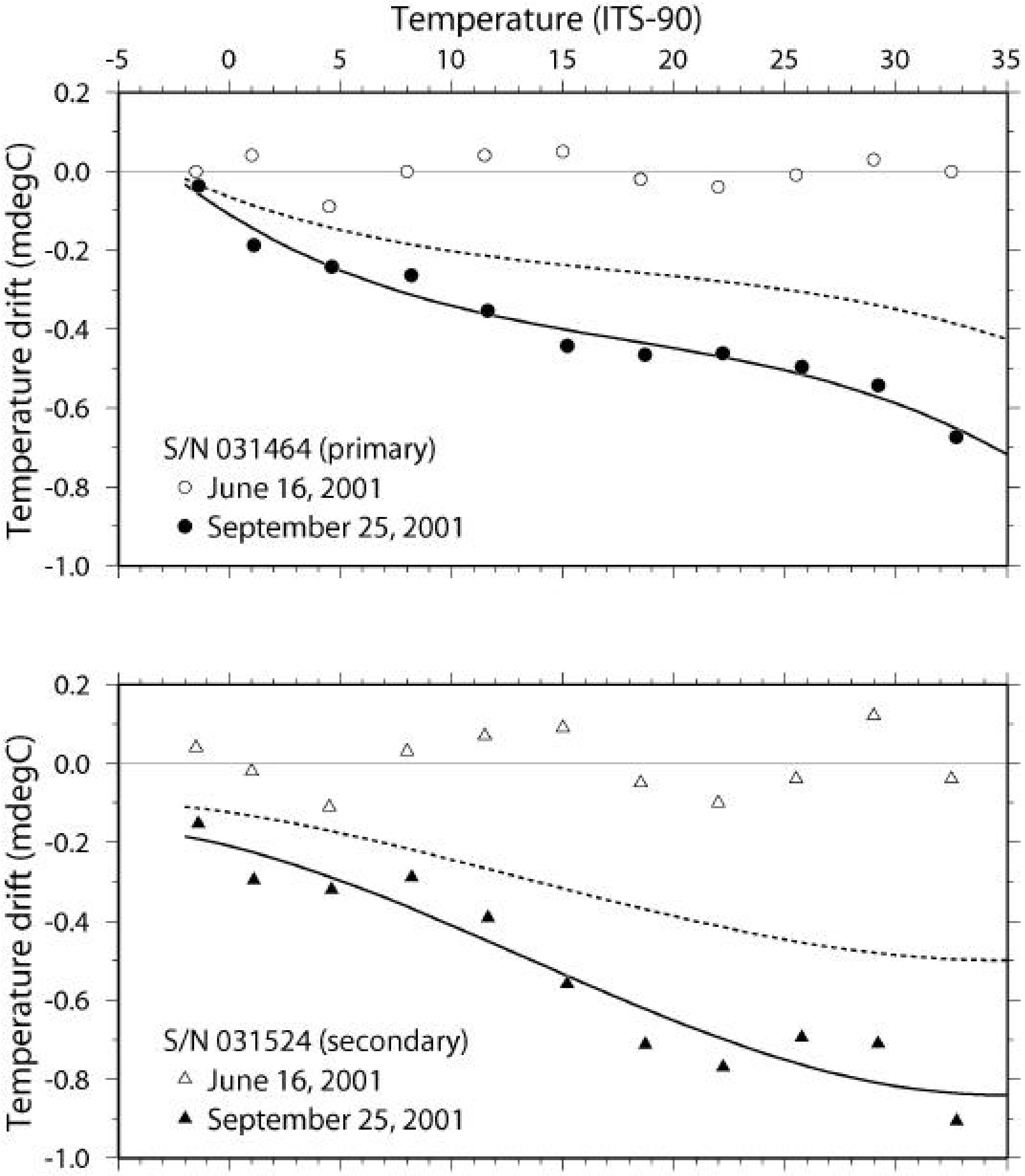

Figure 3: Temperature sensor drift between the pre-cruis calibration and the post-cruise calibration. Dotted line shows estimated drift at August 15, 2001. Upper panel is for the primary sensor and lower panel is for the secondary sensor.

(3) Salinity calibration

The discrepancies of the CTD salinity from the bottle salinity showed each linear behavior against the pressure at the depths upper and lower than about 2000 dbar, separately. Therefore the CTD salinity can be calibrated as

$$\text{Calibrated salinity} = s - (a0 + b0 * p) \quad [\text{when } p < pr]$$

$$= s - (a1 + b1 * p) \quad [\text{when } p >= pr]$$

$$a0 + b0 * pr = a1 + b1 * pr$$

where s is CTD salinity, p is CTD pressure in dbar, pr is the bordering pressure in dbar (i.e. about 2000 dbar) and a0, b0, a1 and b1 are calibration coefficients. The best fit sets of coefficients are determined by minimizing the sum of absolute deviation from the bottle salinity data. Fortran routine MEDFIT in the Numerical Recipies (Press et al., 1986) is used with a slight modification to determine the sets. The coefficients of a1 and b1 are determined first then the coefficients of a0 and b0 are determined with a restriction that the two equations take same value at a pressure of pr.

The pr is set to 2000 dbar. The coefficients are determined for each station. For the station P17N 96, 98 and 99, only coefficients of a0 and b0 are determined with no restriction because the maximum pressure is shallower than 2000 dbar. The CTD data created by the software module ROSSUM are used after the post-cruise calibration for the CTD pressure and temperature. The calibration is performed for the CTD salinity calculated from the primary temperature and the primary conductivity sensor data. For depths where the vertical salinity gradient calculated from the up cast CTD data as greater than 0.003 (per dbar), bottle salinity data are not used for calibration because of the ambiguity resulted from the vertical separation of the bottles and CTD sensors. Nevertheless, for the station P17N 98 and 99, the threshold is enlarged to 0.01 and 0.03, respectively, because vertical salinity gradients greater than 0.003 (per dbar) at most of depths of observation.

The calibration coefficients, the mean absolute deviation (dev) from the bottle salinity and the number of the data (n) used for the calibration are as follows:

	[P < pr]				[p >= pr]			
Station	a0	b0	dev	n	a1	b1	dev	n
P17C 26 1	-0.00323796359	8.36601939e-07	0.0037	19	-0.00271393877	5.74589528e-07	0.0002	11
P17C 25 1	-0.00257052449	8.82155636e-07	0.0014	16	-0.00132877162	2.61279201e-07	0.0002	13
P17C 24 1	-0.00331067064	1.16289883e-06	0.0016	16	-0.00184117328	4.28150144e-07	0.0003	12
P17C 23 1	-0.00382368966	1.40692913e-06	0.0015	16	-0.00179434874	3.92258671e-07	0.0001	12
P17C 22 1	-0.00326188564	1.41985481e-06	0.0007	15	-0.00096517101	2.71497497e-07	0.0002	12
P17C 21 1	-0.00319830505	1.43389220e-06	0.0017	17	-0.00147579046	5.72634908e-07	0.0003	11
P17C 20 1	-0.00261318529	1.00304935e-06	0.0011	15	-0.00138810474	3.90509077e-07	0.0002	12
P17C 19 1	-0.00202409855	1.25230270e-06	0.0029	14	-0.00004195469	2.61230772e-07	0.0003	15
P17C 18 1	-0.00283864140	1.71584117e-06	0.0026	13	+0.00002441331	2.84313809e-07	0.0001	15

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P17N 28 1 -0.00112514634 7.56885977e-07 0.0021 15 -0.00055319685 4.70911231e-07 0.0002 15
P17N 29 1 -0.00370425677 2.22804475e-06 0.0029 12 +0.00017592133 2.87955697e-07 0.0002 15
P17N 30 1 -0.00280488879 1.69012529e-06 0.0036 16 -0.00044555799 5.10459893e-07 0.0002 15
P17N 31 1 -0.00098135226 9.06224203e-07 0.0010 16 +0.00022851796 3.01289096e-07 0.0002 15
P17N 32 1 -0.00126321674 8.70164912e-07 0.0013 18 -0.00005488577 2.65999429e-07 0.0002 14
P17N 33 1 -0.00100392508 7.57475347e-07 0.0017 17 -0.00017721020 3.44117904e-07 0.0002 15
P17N 34 1 -0.00210535284 1.44937246e-06 0.0022 14 +0.00024544860 2.73971739e-07 0.0001 15
P17N 35 1 -0.00100620500 8.98826507e-07 0.0021 19 +0.00009644912 3.47499447e-07 0.0002 13
P17N 36 1 -0.00084307915 8.22056902e-07 0.0011 17 +0.00003336582 3.83834416e-07 0.0002 12
P17N 37 1 -0.00206571751 1.65780681e-06 0.0008 14 +0.00086308272 1.93406694e-07 0.0002 12
P17N 38 1 -0.00274848175 1.90594484e-06 0.0027 18 +0.00043136806 3.16019935e-07 0.0001 13
P17N 39 1 -0.00219115023 1.59192468e-06 0.0015 16 +0.00043326578 2.79716674e-07 0.0002 13
P17N 40 1 -0.00480874195 2.84841427e-06 0.0018 20 -0.00002631819 4.57202389e-07 0.0001 10
P17N 42 1 -0.00364456318 2.16124869e-06 0.0028 21 -0.00103968629 8.58810246e-07 0.0001 10
P17N 43 1 -0.00187164002 1.22702118e-06 0.0030 16 -0.00104440142 8.13401881e-07 0.0001 10
P17N 44 1 -0.00301327646 1.75063559e-06 0.0020 18 -0.00049127870 4.89636713e-07 0.0001 11
P17N 45 1 -0.00221023727 1.31971058e-06 0.0009 18 -0.00081721950 6.23201692e-07 0.0002 11
P17N 46 1 -0.00351928388 2.21918435e-06 0.0029 20 +0.00018003287 3.69525974e-07 0.0001 11
P17N 47 1 -0.00149713124 1.16861624e-06 0.0013 20 +0.00022286518 3.08618031e-07 0.0001  8
P17N 48 1 -0.00739143072 4.18611668e-06 0.0035 22 -0.00003244765 5.06625144e-07 0.0006  9
P17N 49 1 -0.00274069485 1.72223501e-06 0.0015 21 -0.00020164018 4.52707674e-07 0.0001 10
P17N 50 1 -0.00179353576 1.30327572e-06 0.0010 20 +0.00005565780 3.78678942e-07 0.0001 10
P17N 51 1 -0.00236921437 1.71007795e-06 0.0019 18 +0.00036073481 3.45103364e-07 0.0002 10
P17N 52 1 -0.00431883257 2.60325069e-06 0.0010 15 -0.00009230456 4.89986690e-07 0.0001 10
P17N 53 1 -0.00389149710 2.36791128e-06 0.0021 22 -0.00051017140 6.77248430e-07 0.0003 11
P17N 54 1 -0.00656862167 3.92821012e-06 0.0033 18 +0.00040671843 4.40540072e-07 0.0001 10
P17N 55 1 -0.00395174000 2.47307957e-06 0.0016 17 +0.00006997511 4.62222014e-07 0.0003 12
P17N 56 1 -0.00424859112 2.54919462e-06 0.0037 16 -0.00045596387 6.52880998e-07 0.0001  9
P17N 57 1 -0.00632590758 3.78120284e-06 0.0024 18 +0.00072592490 2.55286594e-07 0.0003  9
P17N 58 1 -0.00391224558 2.51015183e-06 0.0010 18 -0.00023526510 6.71661595e-07 0.0002 12
P17N 59 1 -0.00648368908 4.00245706e-06 0.0030 18 +0.00115609924 1.82562902e-07 0.0006 10
P17N 60 1 -0.00619373052 3.53760486e-06 0.0018 17 -0.00012297052 5.02224860e-07 0.0002 12
P17N 61 1 -0.00287315314 2.23506005e-06 0.0011 19 +0.00064993799 4.73514483e-07 0.0002 13
P17N 62 1 -0.00579580478 3.62060307e-06 0.0011 17 +0.00042784185 5.08779752e-07 0.0002 12
P17N 63 1 -0.00380900743 2.34187157e-06 0.0019 20 -0.00102612201 9.50428857e-07 0.0002 13
P17N 64 1 -0.00557255381 3.40483902e-06 0.0015 18 +0.00002883384 6.04145195e-07 0.0002 12
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P17N X01 1 -0.00492856194 3.33574011e-06 0.0011 14 +0.00087074293 4.36087680e-07 0.0002 14
P17N 65 1 -0.00672411653 4.32041464e-06 0.0015 16 +0.00107943845 4.18637148e-07 0.0002 13
P17N 66 1 -0.00433764720 3.06272946e-06 0.0013 15 +0.00089342267 4.47194522e-07 0.0002 13
P17N 67 1 -0.00363321500 2.68804962e-06 0.0012 16 +0.00062632815 5.58278049e-07 0.0002 12
P17N 68 1 -0.00289688175 2.50376971e-06 0.0009 16 +0.00124164132 4.34508177e-07 0.0002 11
P17N 69 1 -0.00206561032 1.82391954e-06 0.0010 17 +0.00011845680 7.31885980e-07 0.0002 13
P17N 70 1 -0.00652305713 4.20119396e-06 0.0027 16 +0.00083172904 5.23800872e-07 0.0001 11
P17N 71 3 -0.00516241726 3.52364120e-06 0.0021 16 +0.00078813535 5.48364888e-07 0.0002 13
P17N 72 1 -0.00260120648 2.47380727e-06 0.0010 19 +0.00164166493 3.52371566e-07 0.0003 13
P17N 73 1 -0.00091898367 1.55554863e-06 0.0007 17 +0.00125905785 4.66527870e-07 0.0002 14
P17N 74 1 -0.00371667927 3.38154846e-06 0.0014 14 +0.00243689634 3.04760658e-07 0.0002 10
P17N 75 1 -0.00486364697 3.37219811e-06 0.0017 16 +0.00041573837 7.32505441e-07 0.0003 14
P17N 76 1 -0.00424812495 3.16531365e-06 0.0010 17 +0.00140274108 3.39880636e-07 0.0001 14
P17N 77 1 -0.00277322927 2.49874131e-06 0.0018 18 +0.00157255241 3.25850470e-07 0.0002 14
P17N 78 1 -0.00317585841 2.74326963e-06 0.0014 18 +0.00144148287 4.34598993e-07 0.0001 11
P17N 79 1 -0.00069385904 1.56374525e-06 0.0007 17 +0.00186176145 2.85935009e-07 0.0001 12
P17N 80 1 -0.00456970497 3.72415366e-06 0.0015 18 +0.00232147753 2.78562409e-07 0.0002 12
P17N 81 1 -0.00211883577 2.35442232e-06 0.0012 17 +0.00188724978 3.51379543e-07 0.0001 12
P17N 82 1 -0.00027518314 1.34440570e-06 0.0009 17 +0.00155926357 4.27182341e-07 0.0001  9
P17N 83 1 -0.00075817689 1.78319230e-06 0.0008 17 +0.00238703497 2.10586372e-07 0.0001 11
P17N 84 1 -0.00172366742 2.10642746e-06 0.0014 19 +0.00166914832 4.10019591e-07 0.0002 10
P17N 86 1 -0.00082332938 1.83224240e-06 0.0017 13 +0.00233071217 2.55221624e-07 0.0001 14
P17N 87 1 -0.00292921563 2.98581447e-06 0.0013 14 +0.00254923496 2.46589172e-07 0.0002 14
P17N 88 1 -0.00107680266 2.10124760e-06 0.0008 12 +0.00279254161 1.66575462e-07 0.0002 17
P17N 90 1 -0.00083228193 1.91158460e-06 0.0019 18 +0.00230746930 3.41708982e-07 0.0001 12
P17N 92 1 -0.00074134491 1.76061628e-06 0.0015 20 +0.00198020219 3.99842728e-07 0.0001 10
P17N 93 1 0.001337410210 9.21610307e-07 0.0012 21 +0.00174232110 7.19154863e-07 0.0001  9
P17N 94 1 -0.00031490228 2.00050960e-06 0.0010 22 +0.00270481639 4.90650267e-07 0.0001  6
P17N 96 2 -0.00195391654 4.17750848e-06 0.0011 16
P17N 98 1 -0.00137970523 2.52920668e-06 0.0023 11
P17N 99 1 -0.00993932076 4.01977009e-06 0.0056  6
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The mean absolute deviation averaged over all stations is as follows:

0.0018 [p < 2000 dbar]

0.0002 [p >= 2000 dbar]

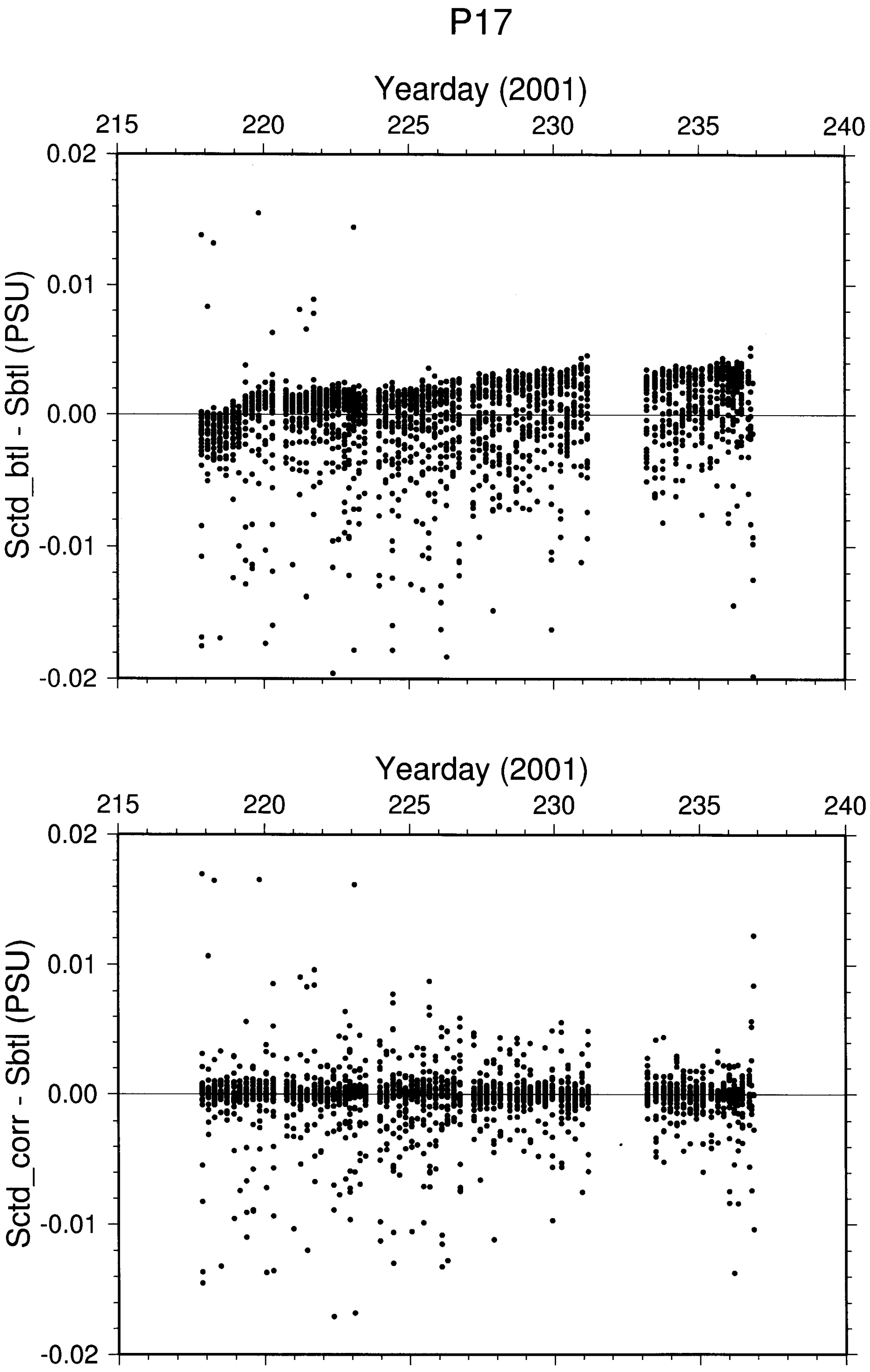

Figure 4: Time series of salinity residuals before (upper panel) and after (lower panel) the calibration.

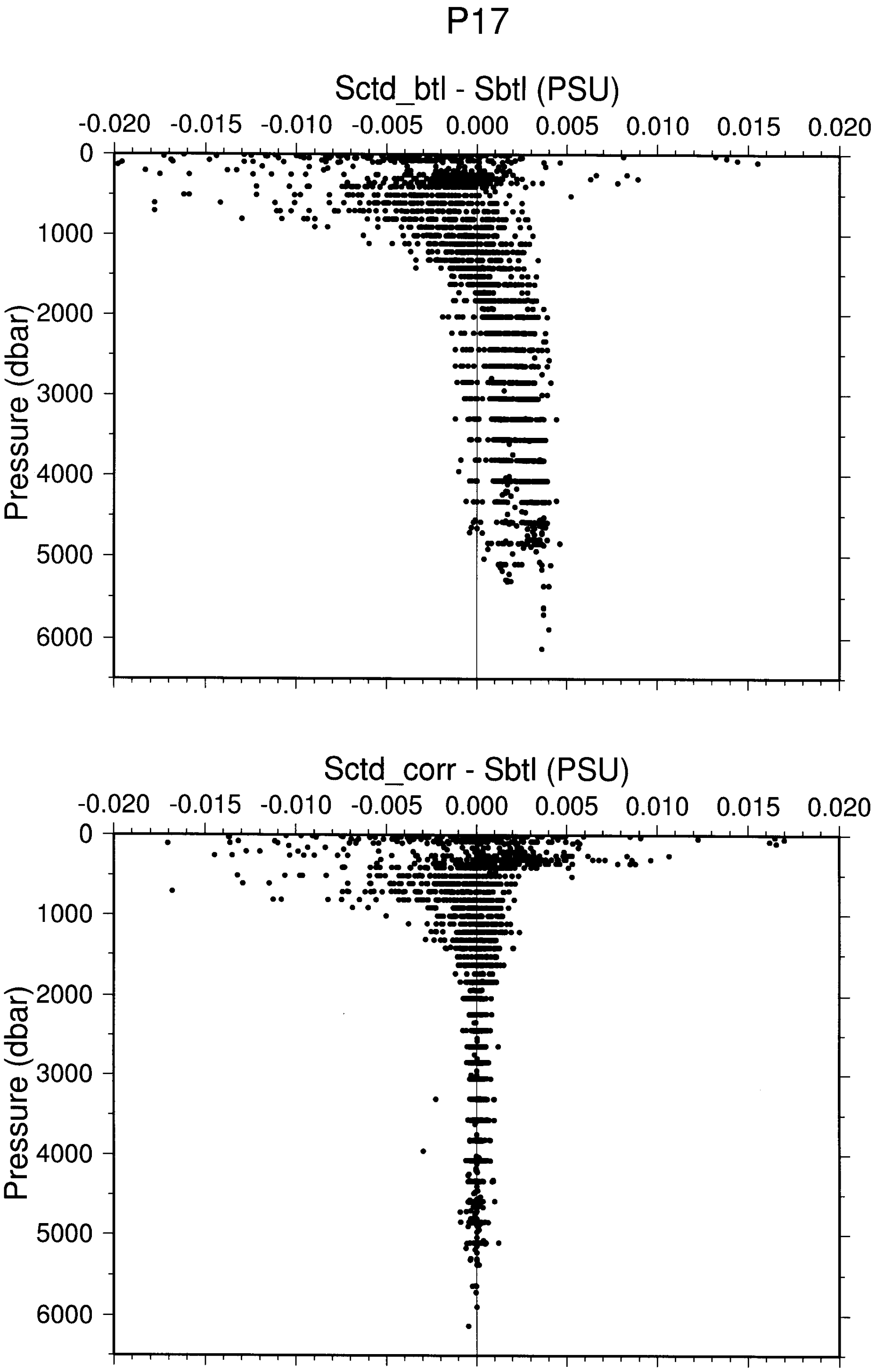

Figure 5: Vertical distribution of salinity residuals before (upper panel) and after (lower panel) the calibration.

(4) Oxygen calibration

The discrepancies of the CTD oxygen (SBE 43) from the bottle oxygen show linear behavior against the bottle oxygen values at depths shallower than about 3000 dbar and against the pressure deeper than about 3000 dbar. Therefore the CTD oxygen is calibrated as

$$\text{Calibrated oxygen} = (a0 + b0 * o) - (a1 + b1 * p)$$

$$a1 = 0,\ b1 = 0 \quad [\text{when } p < pr]$$

$$a1 + b1 * pr = 0$$

where o is CTD oxygen in micro-mol/kg, p is CTD pressure in dbar, pr is the bordering pressure (about 3000 dbar) in dbar and a0, b0, a1, b1 are the calibration coefficients. The best fit sets of coefficients are determined by minimizing the sum of absolute deviations from the bottle oxygen data. Fortran routine MEDFIT in the Numerical Recipies (Press et al., 1986) is used with a slight modification to determine the coefficients. The coefficients a0 and b0 are determined first then the coefficients a1 and b1 are determined with a restriction that the two equations take same value at a pressure of pr.

(A calibration with the coefficients a0 and b0 in above equation may correspond to that with the coefficients of Soc and Offset (see 3-4 and 3-5) in the oxygen model. Although a calibration with Soc and Offset should be essential, the pressure dependency mentioned above could not be retrieved with sufficient accuracy through such a calibration. Therefore the simple linear calibration equations are used to calibrate the CTD oxygen.)

The pr was set to 2500 dbar or 3000 dbar. The coefficients are determined at each station. The deviation of CTD oxygen from the bottle oxygen at depth shallower than 800 dbar is too large to determine a proper sets of the coefficients since the vertical oxygen gradient is strong in the regions. So the coefficients a0 and b0 are determined using the data in the pressure range from 800 dbar to pr. Nevertheless, for the station P17N 96, 98 and 99, the coefficients of a0 and b0 are determined using the data in the whole pressure range because the numbers of bottle oxygen data were small. The down cast CTD data were used after the post-cruise calibration for CTD pressure, temperature and salinity. For depths where the vertical oxygen gradient calculated from the down cast CTD data as greater than 5 micro-mol/kg, bottle oxygen data are not used for calibration because of the ambiguity resulted from the vertical separation of the bottles and CTD sensors.

The pr, the calibration coefficients, the mean absolute deviation from the bottle oxygen and the number of available data for the calibration are as follows:

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dev and n: the mean absolute deviation and the number of the data [p < 800 dbar]
dev0 and n0: the mean absolute deviation and the number of the data [pr > p >= 800 dbar]
dev1 and n1: the mean absolute deviation and the number of the data [p >= pr]

Station    pr    a0           b0           dev   n  dev0 n0   a1         b1            dev1 n1
------------------------------------------------------------------------------------------------
P17C 26 1 3000 -6.099360405 1.040369946  6.86 13 0.94 14 -10.9299107 0.00364330357 0.35 7
P17C 25 1 3000 -8.971520275 1.075145280  7.44 12 0.42 13 -14.4504841 0.00481682805 0.50 8
P17C 24 1 3000 -5.529627844 1.028365598  4.53 14 0.68 14 -6.77747736 0.00225915912 0.40 7
P17C 23 1 3000 -7.386595950 1.047246541  4.23 12 0.28 11 -7.53960919 0.00251320306 0.22 6
P17C 22 1 3900 -7.305887486 1.049203595  4.80 14 0.50 11 -8.46202316 0.00282067439 0.35 8
P17C 21 1 3000 -9.059589750 1.070725686  5.07 14 0.84 14 -12.5271348 0.00417571159 0.70 6
P17C 20 1 2500 -7.576914038 1.062166023  3.99 12 0.65 10 -7.26808020 0.00290723208 0.27 9
P17C 19 1 3000 -6.888153605 1.050814179  3.54 14 0.87 11 -10.0069168 0.00333563892 0.34 10
P17C 18 1 2500 -8.676846720 1.091437969  7.52 12 0.44 08 -10.2718365 0.00410873459 0.55 10
P17N 28 1 2500 -8.949509795 1.095178051  6.29 13 0.24 10 -11.7304995 0.00469219980 0.83 12
P17N 29 1 2500 -10.71553764 1.108806876  6.21 11 1.10 08 -13.9391875 0.00557567501 0.80 12
P17N 30 1 3000 -9.991639224 1.076033076  2.98 12 0.31 10 -13.9476730 0.00464922434 0.41 10
P17N 31 1 3000 -8.781873275 1.059551905  8.41 13 0.31 11 -12.3603037 0.00412010122 0.67 10
P17N 32 1 3000 -7.409800688 1.031783329  4.84 11 0.50 13 -6.89646032 0.00229882011 0.68 9
P17N 33 1 3000 -8.873530679 1.060111768  6.25 14 0.62 11 -13.8277935 0.00460926451 0.43 10
P17N 34 1 3000 -10.31154992 1.091510132  8.47 12 0.75 11 -19.6614446 0.00655381487 0.70 10
P17N 35 1 3000 -9.084332713 1.046265000  5.97 14 0.57 13 -8.88625332 0.00296208444 0.43 8
P17N 36 1 3000 -9.399049595 1.056992029  6.70 11 0.64 13 -11.9565125 0.00398550416 0.46 7
P17N 37 1 3000 -8.364248414 1.042942612  2.91 10 0.35 12 -8.37163711 0.00279054570 0.62 6
P17N 38 1 3000 -10.13053131 1.073233270  4.53 12 0.79 12 -16.4941999 0.00549806665 0.52 9
P17N 39 1 3000 -9.434457480 1.055735385  7.58 11 0.73 14 -12.2868186 0.00409560619 0.47 8
P17N 40 1 3000 -8.422725258 1.043201281  5.09 11 0.82 17 -10.8458844 0.00361529479 0.48 5
P17N 42 1 3000 -10.24374321 1.058984335  4.74 11 0.93 18 -16.0869251 0.00536230838 0.31 3
P17N 43 1 3000 -9.382698183 1.062958957  5.26 11 0.49 14 -18.7986256 0.00626620852 0.53 5
P17N 44 1 3000 -9.981734298 1.061992123  5.80 14 0.29 16 -12.6278156 0.00420927187 0.20 6
P17N 45 1 3000 -10.58694741 1.067900558  3.96 11 0.49 15 -14.4999088 0.00483330294 0.29 6
P17N 46 1 3000 -8.581704444 1.035389951  7.26 14 0.53 14 -6.65999935 0.00221999978 0.40 6
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P17N 47 1 3000 -9.576965449 1.050655685  5.16 14 0.69 14 -8.81065801 0.00293688600 0.28 5
P17N 48 1 3000 -9.473259386 1.047975147  8.31 11 0.52 16 -7.72022568 0.00257340856 0.34 5
P17N 49 1 2500 -9.834545198 1.081214717  6.36 14 0.41 14 -11.3991842 0.00455967368 0.26 6
P17N 50 1 2500 -10.10495099 1.095254233  8.22 09 0.37 11 -13.5234429 0.00540937715 0.90 6
P17N 51 1 2500 -9.638736644 1.081947704  2.00 11 0.43 12 -11.3137098 0.00452548393 0.49 7
P17N 52 1 3000 -8.121769450 1.044767285  6.81 09 0.61 13 -11.1193260 0.00370644201 0.38 3
P17N 53 1 3000 -9.604492361 1.067672633  5.95 13 0.68 16 -15.5654310 0.00518847700 0.73 5
P17N 54 1 3000 -10.28221502 1.064388502  4.91 10 0.83 13 -11.5592357 0.00385307857 0.45 4
P17N 55 1 3000 -8.215101362 1.056469182  2.18 11 0.95 14 -15.7699668 0.00525665560 0.42 7
P17N 56 1 3000 -9.791078427 1.057042803  2.86 12 0.73 15 -10.5405558 0.00351351859 0.24 6
P17N 57 1 3000 -10.66876483 1.080050297  5.21 12 0.35 13 -16.4940112 0.00549800374 0.54 6
P17N 58 1 2500 -10.76470289 1.100402187  5.59 14 0.71 11 -13.8494455 0.00553977820 0.66 9
P17N 59 1 2500 -10.53793839 1.092647127  5.34 14 0.65 13 -12.2999378 0.00491997513 0.72 9
P17N 60 1 3000 -9.836038299 1.064379433  2.11 13 0.34 13 -12.3644234 0.00412147447 0.69 7
P17N 61 1 3000 -9.408143455 1.056110095  5.71 12 0.35 14 -10.7805048 0.00359350161 0.26 8
P17N 62 1 3000 -9.923429623 1.073515852  3.87 11 0.64 13 -15.2642608 0.00508808694 0.35 8
P17N 63 1 3000 -9.557855591 1.048627293  6.34 14 0.28 13 -11.5186339 0.00383954465 0.33 7
P17N 64 1 3000 -9.740348640 1.088424387  4.00 13 0.31 13 -21.7283223 0.00724277409 0.41 7
P17N X01 1 3000 -8.371952559 1.038180592 8.83 13 0.60 09 -9.78801865 0.00326267288 0.69 9
P17N 65 1 3000 -9.551040280 1.079632823 11.09 11 0.60 11 -19.3524499 0.00645081664 0.76 8
P17N 66 1 3000 -10.27693516 1.091416152  6.31 11 0.53 13 -21.3706714 0.00712355714 0.44 8
P17N 67 1 3000 -9.412121367 1.075727953  3.39 13 0.55 12 -16.9440724 0.00564802414 0.43 7
P17N 68 1 3000 -8.714350922 1.060143438  7.42 10 0.57 14 -13.7545611 0.00458485371 0.31 6
P17N 69 1 3000 -9.408301211 1.071835344  8.02 13 0.78 14 -15.8136664 0.00527122215 0.53 8
P17N 70 1 3000 -10.32013012 1.076201596  6.76 11 0.56 12 -15.4215410 0.00514051366 0.41 7
P17N 71 3 3000 -8.919832027 1.050925439  4.18 10 0.45 13 -11.2263973 0.00374213242 0.20 8
P17N 72 1 3000 -9.052916259 1.047460170  8.98 14 0.49 14 -11.6939781 0.00389799269 0.18 8
P17N 73 1 3000 -9.219642560 1.073557224  6.08 12 0.61 13 -17.2527649 0.00575092164 0.58 9
P17N 74 1 3000 -8.775778186 1.060304930  6.37 11 0.25 11 -13.9816700 0.00466055667 0.20 7
P17N 75 1 3000 -9.997667857 1.075134400  5.43 12 0.51 12 -16.9202792 0.00564009308 0.61 9
P17N 76 1 3000 -8.990971722 1.042222397  7.76 14 0.40 13 -15.4331625 0.00514438751 1.16 9
P17N 77 1 3000 -9.710916843 1.060383262  3.41 11 0.47 13 -13.6283141 0.00454277136 0.29 9
P17N 78 1 3000 -8.568935573 1.044311498  4.35 11 0.47 12 -12.0664230 0.00402214101 0.23 8
P17N 79 1 3000 -8.738046345 1.043973027  4.87 13 0.50 14 -13.4045628 0.00446818759 0.38 7
P17N 80 1 3000 -8.097798952 1.043270916  4.01 10 0.54 14 -12.2593489 0.00408644964 0.34 8
P17N 81 1 3000 -9.233743802 1.053771754  3.80 14 0.68 12 -16.4023224 0.00546744080 0.29 8
```

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P17N 82 1 3000 -8.881406499 1.051434887  7.17 11 0.28 13 -15.1862347 0.00506207823 0.24 7
P17N 83 1 3000 -7.975074171 1.028412310  4.26 10 0.47 13 -6.97467826 0.00232489275 0.26 7
P17N 84 1 3000 -9.985211184 1.057807940  5.17 12 0.43 13 -12.9007483 0.00430024945 0.39 8
P17N 86 1 3000 -10.19567244 1.043387069  5.30 09 0.56 10 -15.2588930 0.00508629768 0.83 10
P17N 87 1 2500 -9.730194504 1.057040862  9.18 09 0.38 09 -9.91423923 0.00396569569 0.56 14
P17N 88 1 2500 -10.41733909 1.063737279 16.76 11 0.23 09 -12.4798272 0.00499193089 1.00 14
P17N 90 1 2500 -12.56598991 1.124036761  3.03 12 0.67 10 -19.9885598 0.00799542391 1.32 10
P17N 92 1 3000 -8.952500275 1.027299076 11.14 13 0.78 16 -1.61467574 0.000538225245 0.56 5
P17N 93 1 3000 -9.686243469 1.043885543  7.03 14 0.78 17
P17N 94 1 3000 -10.52427791 1.049230691  8.71 17 0.48 16
P17N 96 2 3000 -10.54840239 1.091405576     *  * 1.59 20
P17N 98 1 3000 -11.10571481 1.094795619     *  * 3.15 17
P17N 99 1 3000 -14.02518652 1.104887956     *  * 6.22 10
-----------------------------------------------------------------------------------------
```

The mean absolute deviation averaged over all stations is as follows:

5.90 micro-mol/kg [p < 800 dbar]
0.68 micro-mol/kg [pr > p >= 800 dbar]
0.49 micro-mol/kg [p >= pr]

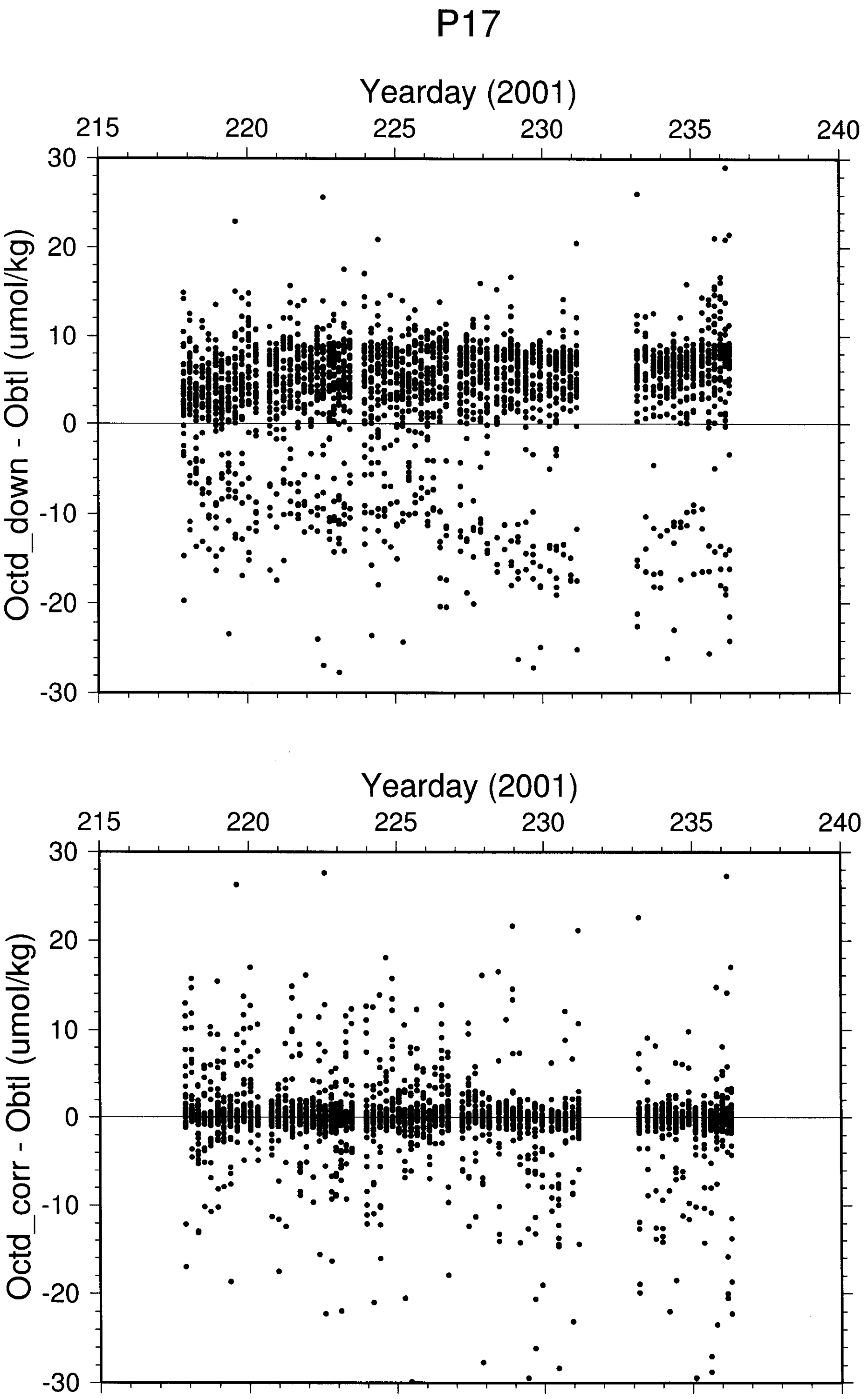

Figure 6: Time series of oxygen residuals before (upper panel) and after (lower panel) the calibration.

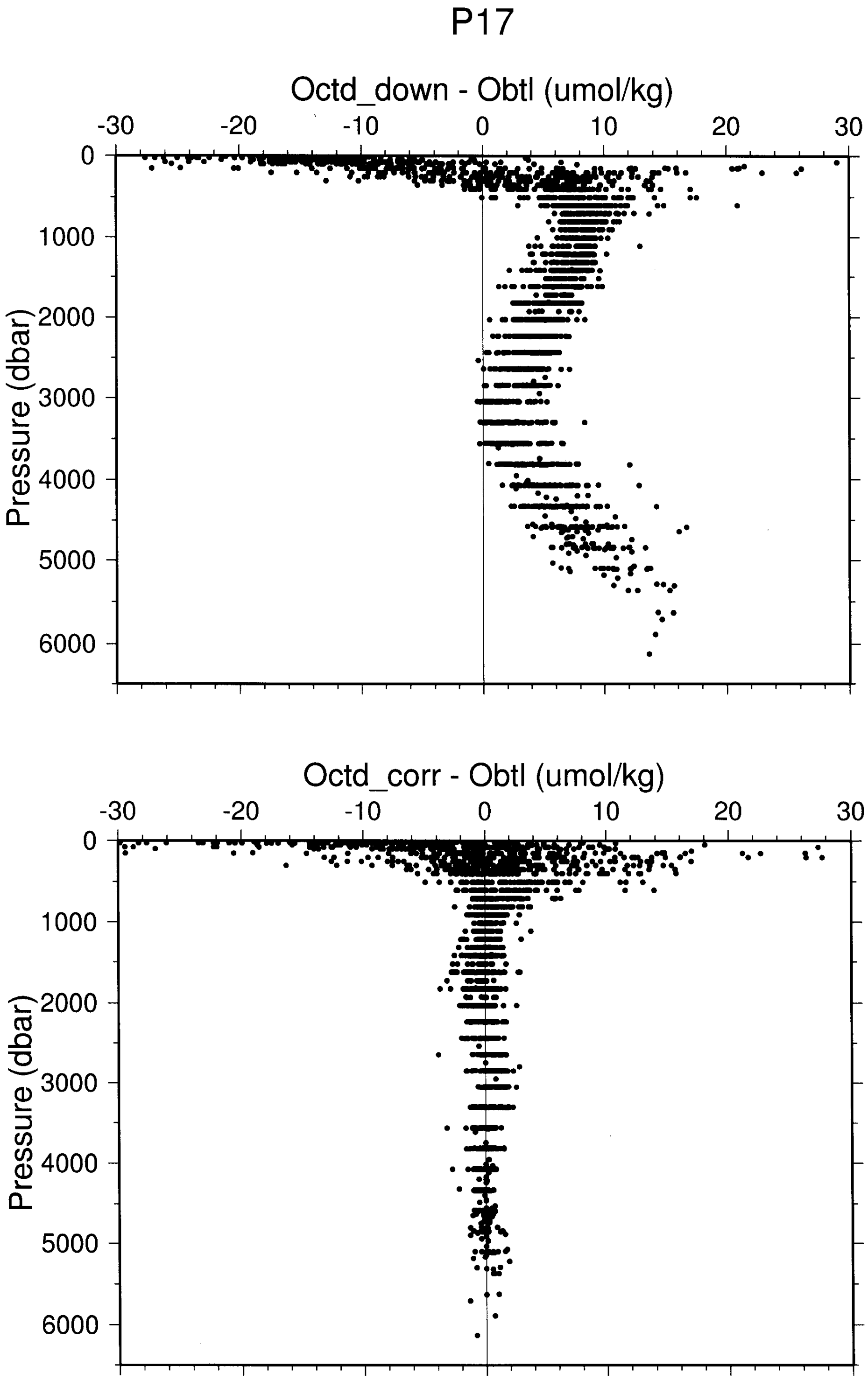

Figure 7: Vertical distribution of oxygen residuals before (upper panel) and after (lower panel) the calibration.