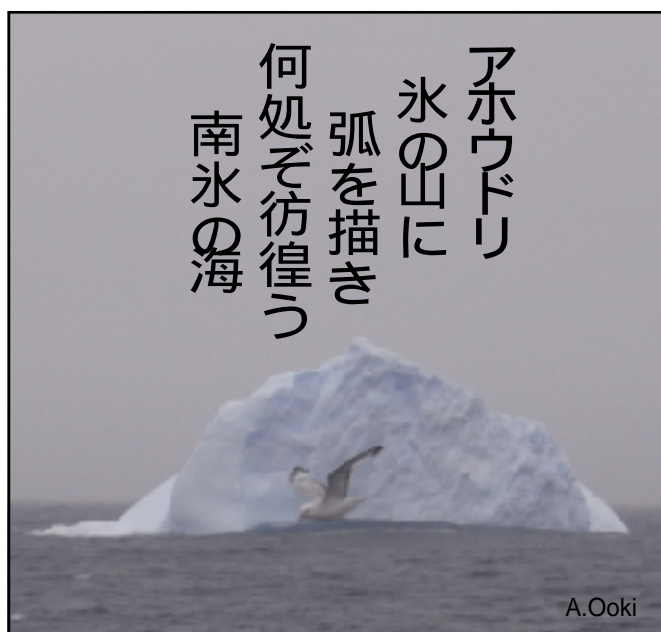


Preliminary Report  
of  
The Hakuho Maru Cruise KH-09-5 Leg1,2,3  
(The Indian Ocean and the Antarctic Sea)  
-ERIDANUS Expedition-

November 6, 2009 -January 9, 2010

Meridional Studies on Biogeochemistry of Trace Elements  
and Isotopes in the Indian Ocean (GEOTRACES)



Ocean Research Institute  
the University of Tokyo  
2010

by  
The scientific Members of the Expedition

Edited by  
Toshitaka GAMO



# Preliminary Report of The Hakuho Maru Cruise KH-09-5, Leg-1, -2, and -3 (The first **GEOTRACES** cruise in the Indian Ocean): ERIDANUS Expedition

November 6, 2009 --- January 10, 2010

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A group photo (leg-2) on board Hakuho Maru

A group photo (leg-3) at the Port of Cape Town

## 1. Introduction

The first three legs of the *Hakuho Maru* KH-09-5 cruise, whose schedules are shown below, were successfully conducted by Ocean Research Institute, the University of Tokyo, and Japan Agency for Marine-Earth Science and Technology (JAMSTEC), from 6 November 2009 to 10 January 2010 (66 days in total) in the north and western Indian Ocean including the Antarctic Sea. We nickname these three legs “ERIDANUS Expedition”.

Leg-1: Tokyo, Japan (6 Nov. 2009) to Cochin, India (24 Nov. 2009)

Leg-2: Cochin, India (27 Nov. 2009) to Port Louis, Mauritius (16 Dec. 2009)

Leg-3: Port Louis, Mauritius (16 Dec. 2009) to Cape Town, South Africa (10 Jan. 2010)

In the original plan, this cruise should have been completed a year earlier (from Nov. 2008 to Jan. 2009), but the cruise was postponed as above due to the rapid increase of oil price at the beginning of FY2008.

This cruise has been internationally authorized as the first GEOTRACES meridional study in the Indian Ocean. GEOTRACES is a “New Wave” of global marine geochemical studies, started in 2005 as one of the large-scale international programs sponsored by SCOR (Scientific Committee on Oceanic Research). GEOTRACES means an international study of the marine biogeochemical cycles of trace elements and their isotopes (TEIs) in a global scale. The determination of trace elements has recently become a central focus of many research programs that seek information on the biogeochemical processes in the ocean. The study of TEIs has graduated from a curiosity to understand how the chemical diversity of trace elements, in their various redox and chemical states, interacts with the physical and biological processes occurring in the ocean. This is particularly important in the case of micronutrients such as Fe, whose oceanic distributions seem to be a crucial link to climatic processes. Together with other biologically required TEIs, perturbations of their cycles induced by the climate change may have fundamental consequences for the global carbon cycle, which is firmly associated with global climate. Although our knowledge on the behavior of TEIs in the ocean is fairly small at the present stage, recent advances on analytical and clean sampling techniques have just enabled us to get precise information on TEIs in the ocean, which is the powerful background to initiate a new international program, GEOTRACES.

As the GEOTRACES initiative in the Indian Ocean, the main study theme of this cruise was marine geochemical observations in the northern (chiefly in the Bengal Bay) and western Indian Ocean from the Arabian Sea to the Antarctic Sea along a meridional line. It is a pity that we had to slightly modify the planned meridional line along 65°E, because of i) the threat of Somalian pirates

in the Arabian Sea, ii) an approaching cyclone in the southern equatorial region, and iii) severe weather condition in the Antarctic Sea. We conducted various observations as described in this report for marine geochemical processes and ocean flux in the Indian Ocean. Our ability to predict the future environmental change caused by the global warming depends upon knowledge on the distribution of biologically important chemical species in the ocean and their exchange flux at the air-sea and sediment-water interfaces. The Indian Ocean occupies a vast area of the world ocean, but little is known about the marine biogeochemical cycles on TEIs. Thus, it is important to understand the role of the Indian Ocean in the global carbon cycle including its temporal variations recorded in marine sediments. Shipboard observation and sampling of water and sediments were made during the cruise and detailed measurements of major and minor chemical components and their isotopes were partly done on board the ship and will be performed in detail on shore-based laboratories after the cruise.

In addition, we conducted intercalibration studies during the cruise, by comparing the GEOTRACES-recommended Kevlar wire hydrocast with the R/V Hakuho Maru's titanium wire hydrocast. We have established a GEOTRACES baseline station at (20°S, 72°33'E) in the central Indian Basin, taking seawater samples not only for shipboard scientists but also for other international scientists who will measure in future some of the GEOTRACES key parameters for intercomparison with our results.

Forty three scientists (including graduate students) from various universities and research institutes in Japan, three technical supporting staffs from Marine Work Japan Ltd., one scientist from U.S.A., one scientist from Canada, two scientists from China, and three scientists from India, total 53 scientists took part in the cruise to pursue international collaborative studies on GEOTRACES. We hope that the obtained data by this cruise will play an important role in the GEOTRACES program as its first accomplishment in the Indian Ocean.

It is our great pleasure to thank Captain Ushio Fujita, the officers and crew of R.V. *Hakuho Maru* for their invaluable collaboration in the successful conduct of all shipboard works. Sincere thanks are also due to Office for Cruise Coordination of Ocean Research Institute, the University of Tokyo, and Research Vessel Operation Department of Japan Agency for Marine-Earth Science and Technology (JAMSTEC) for their great efforts to support the cruise.

Toshitaka Gamo (Chief Scientist of the Leg-2 and -3)  
Hajime Obata (Chief Scientist of the Leg-1)  
and the Shipboard Scientific Party

## **2. Caution about the cruise data**

### **2-1. General rules**

Data in this preliminary report should be treated as carefully as possible, in order to protect the priority of the participants of the KH-09-5 cruise Leg 1 to 3.

Confidential and publication policies are as follows, mainly according to the data policy provided by the Steering Committee on Cooperative Studies using research vessels Hakuho Maru and Tansei Maru:

(1) No one other than the cruise participants can submit papers or give oral presentations using any data in this report within two years after the end of the cruise.

(2) Although all data included in this report is common to the cruise participants, primary investigators of each study item have higher priority to use them.

(3) Any information on the release of the cruise data (oral presentations, publications of papers, etc.) by the cruise participants should be sent to the chief scientists and the Office for Cruise Coordination of Ocean Research Institute, the University of Tokyo.

(4) Any questions or problems on the publication policy should be forwarded to the chief scientists.

There may be some misprints or mistakes to be corrected later in this report. If any misprint or mistake is found, kindly inform the chief scientists, who are responsible for distributing the correct data to the cruise participating GEOTRACERS.

### **2-2. GEOTRACES Data Policy** (from <http://www.bodc.ac.uk/geotraces/data/policy/>)

GEOTRACES seeks, on the one hand, protection of the intellectual effort and time of originating investigators (those who plan an experiment, collect, calibrate, and process a data set to answer some questions about the ocean), and on the other hand, the need to compare various data sets and data types to check their consistency, to better understand the ocean processes involved, and to see how well the numerical models describe the real ocean. We stress that data will not be released within the proprietary period (see below) without the permission of the originator.

#### **Data/Metadata Submission** (timeline):

- As soon as a cruise is organised: **Precruise metadata** to be submitted to GEOTRACES IPO and GDAC.
- Within one week of cruise completion:  
Submit Postcruise metadata forms from chief scientist

Submit electronic versions (scanned or original) of event log and log sheets

Submit copy of **ROSCOP/CSR** form where one is required by ship operator

- Within 6 months of end of cruise:

Chief scientist submits cruise report, where one is required by ship operator.

Data and metadata for shared ancillary parameters (e.g., nutrients) submitted to DAC\*.

Submit CTD and underway data (both raw and processed files; sensor information and calibration) to national DAC (e.g., BCO-DMO) and BODC.

- As soon as possible, after the proprietary period (see below):

Submit all data sets and accompanying metadata to DAC\*

(\*DAC: In most cases, data will be submitted initially to a national data centre (DAC). Where no national DAC is available, information should be submitted directly to the GDAC at BODC. In case of Japan, JODC plays a role as DAC. )

#### **Data Access (timeline):**

- Precruise metadata will be publicly accessible (GDAC web site) as soon as it is available
- Any metadata and data produced during the cruise/process study should be made available to participating scientists immediately in preliminary form during the cruise/process study.
- Any data generated from a cruise and submitted to the DAC will be password protected and available only to registered users (data originators and their designated collaborators) until the public release date.

Prior to public release, all data will be considered preliminary. Data should be shared with other cruise/process study participants as soon as they become available during or after a cruise or process study, to enable data synthesis to proceed rapidly, with the understanding that the data are the proprietary material of the originating scientist and may not be used without their permission. However, for non-participating scientists the data can be obtained only with the permission of the responsible participating scientist.

#### **Proprietary period**

Most nations have rules about data release that are imposed by funding agencies. GEOTRACES will adhere to these rules. In addition, we expect that all data will be released within two years of data generation, or at the time of publication (whichever is sooner). Exceptions are possible in the case of data forming a part of a student's thesis.

Adherence to this data policy is expected of all scientists participating in national and international GEOTRACES activities. Exceptions to this GEOTRACES policy may be allowed; e.g., where the policy is overridden by national constraints on data access.

### 3-1. KH-09-5 Scientist List

	Family name	Given name	Affiliation	Leg-1	Leg-2	Leg-3
1	GAMO	Toshitaka	Univ. Tokyo		◎	◎
2	OBATA	Hajime	Univ. Tokyo	◎	○	○
3	AMAKAWA	Hiroshi	Univ. Tokyo			○
4	NAKAYAMA	Noriko	Univ. Tokyo	○	○	○
5	IMAI	Keiri	Univ. Tokyo	○	○	○
6	ISHIGAKI	Hideo	Univ. Tokyo	○	○	○
7	MASE	Akira	Univ. Tokyo	○	○	
8	OGURA	Takeshi	Univ. Tokyo	○	○	
9	TOYOSHIMA	Kosaku	Univ. Tokyo	○		
10	KIM	Tae Jin	Univ. Tokyo	○	○	○
11	SHIOZAKI	Takuhei	Univ. Tokyo	○	○	
12	KODAMA	Taketoshi	Univ. Tokyo	○	○	○
13	SHIRAI	Kotaro	Univ. Tokyo		○	
14	MATSUZAKI	Hiroyuki	Univ. Tokyo		○	
15	NISHIOKA	Jun	Hokkaido Univ.		○	○
16	OHMORI	Kazuto	Hokkaido Univ.		○	○
17	DAITA	Satoko	Hokkaido Univ.		○	○
18	TAKAHASHI	Yuko	Ishinomaki Senshu Univ.			○
19	TAZOE	Hirofumi	Nihon Univ.	○	○	○
20	YAMAGATA	Takeyasu	Nihon Univ.			○
21	SATO	Hiromi	Nihon Univ.	○		
22	HANYU	Tomoko	Grad. Univ. Adv. Studies			○
23	KATO	Yoshihisa	Tokai Univ.			○
24	SAKAMOTO	Midori	Tokai Univ.		○	○
25	MINAMI	Hideki	Tokai Univ.		○	
26	YAMADA	Yukako	Tokai Univ.	○	○	
27	NORISUYE	Kazuhiro	Kyoto Univ.	○	○	
28	FIRDAUS	Lufti Mochamad	Kyoto Univ.			○
29	MORISHIMA	Yui	Kyoto Univ.	○	○	
30	HUONG	Vu Thi Dieu	Kyoto Univ.			○
31	NAKAGUCHI	Yuzuru	Kinki Univ.	○		
32	TAKEUCHI	Makoto	Kinki Univ.	○	○	○
33	ASATANI	Takuya	Kinki Univ.		○	○
34	MURAYAMA	Masafumi	Kochi Univ.		○	○
35	SAKAMOTO	Tetsuhiro	Kochi Univ.	○	○	○
36	TOYOMURA	Katsunori	Kochi Univ.			○
37	TAKEDA	Shigenobu	Nagasaki Univ.	○	○	
38	NOGI	Yoshifumi	Natl. Inst. Polar Res.			○
39	YAMASHITA	Nobuyoshi	Natl. Inst. Adv. Ind. Sci. Tech.		○	○
40	TANIYASU	Sachi	Natl. Inst. Adv. Ind. Sci. Tech.		○	
41	SASANO	Daisuke	Meteorol. Res. Inst.			○
42	OHKI	Atsushi	Natl. Inst. Environ. Sci.	○	○	○
43	KAWAGUCCI	Shinsuke	JAMSTEC		○	
44	KONDO	Yoshiko	Univ. Southern California		○	
45	LI	Qian	Xiamen Univ.	○		
46	ZHENG	Nan	Xiamen Univ.	○		
47	KAWAI	Michiyo	Inst. Ocean Sci., Canada	○		
48	SARMA	V.V.S.S.	Natl. Inst. Oceanogr., India		○	
49	GOSWAMI	Vineet	Phys. Res. Lab., India		○	
50	BHUSHAN	Ravi	Phys. Res. Lab., India			○
51	YOSHIDA	Kazuhiro	Marine Works Japan Ltd.	○		
52	SATO	Yusuke	Marine Works Japan Ltd.		○	
53	TAKETOMO	Yohei	Marine Works Japan Ltd.			○
				24	34	30

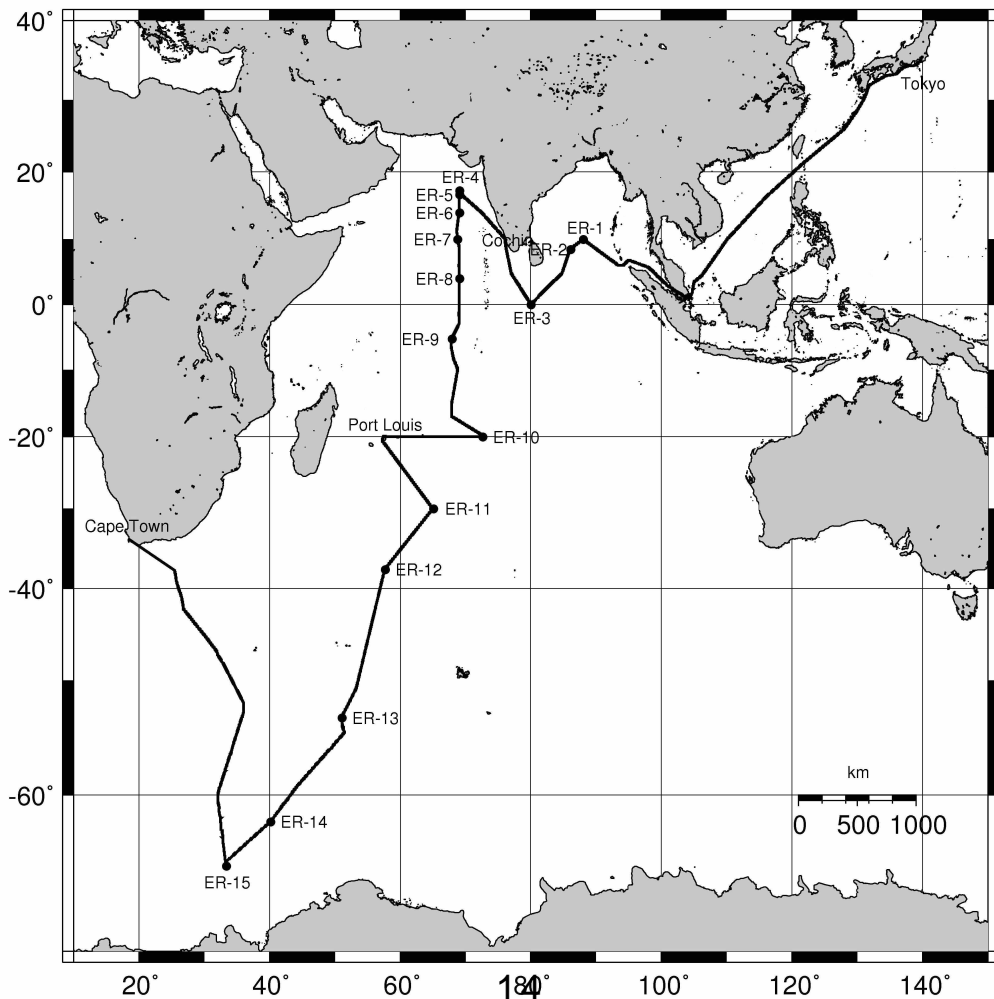


### 3-2. KH-09-5 Crew List

	Family name	Given name	Rating	Leg-1	Leg-2	Leg-3
1	FUJITA	Ushio	Master	○	○	○
2	OKUBO	Suguru	Chief Officer	○	○	
3	KASUGA	Kazuhiko	Chief Officer			○
4	INOUE	Takamichi	First Officer	○	○	○
5	SATO	Makoto	Second Officer	○	○	
6	KIYOMIYA	Tomonori	Second Officer			○
7	SAMMORI	Yasuhiko	J. Second Officer	○	○	○
8	CHIBA	Masato	Third Officer	○	○	○
9	YOSHIDA	Satoru	J. Third Officer	○	○	○
10	IKEDA	Hiroe	Boatswain	○	○	○
11	SUGAWARA	Shinichi	Second Boatswain	○	○	○
12	NISHIDATE	Shintaro	Quarter Master			○
13	KAWANA	Yukio	Quarter Master	○	○	○
14	ITAHASHI	Kazuhiko	Quarter Master	○	○	
15	HOSOKAWA	Seiji	Quarter Master	○	○	○
16	TERASAKA	Yukihiro	Quarter Master	○	○	○
17	YOSHIDA	Takumi	Quarter Master	○	○	○
18	UENO	Shinya	Sailor	○	○	
19	KIMURA	Tomohiro	Sailor			○
20	HIROSAWA	Seiji	Chief Engineer	○	○	○
21	TAKAHASHI	Yoshimitsu	First Engineer	○	○	○
22	FUNATSU	Hironori	J. First Engineer	○	○	○
23	KUROSE	Wataru	Second Engineer	○	○	
24	SAKUMA	Yasuhiro	Second Engineer			○
25	KIUCHI	Toshio	J. Second Engineer	○	○	○
26	KURATOMI	Hozumi	Third Engineer	○	○	
27	YAMAMURA	Takatoshi	Third Engineer			○
28	OKAZAKI	Hiroyuki	No. 1 Oiler	○	○	○
29	SATO	Masayoshi	No. 2 Oiler	○	○	○
30	YOSHIDA	Minoru	No. 3 Oiler	○	○	○
31	YOSHIDA	Sakae	No. 4 Oiler	○	○	
32	YAMANAKA	Takahiro	No. 4 Oiler			○
33	YAMAGUCHI	Yukihiro	No. 5 Oiler	○	○	○
34	ABE	Yu	No. 6 Oiler	○	○	○
35	SUZUKI	Ryota	No. 7 Oiler	○	○	○
36	TANIGUCHI	Keiya	Machine Man	○	○	○
37	KANEKO	Yasuo	Chief Electronics Officer	○	○	○
38	YAMASHITA	Toru	Chief Electronics Officer			○
39	HASHIMOTO	Kikuo	Second Electronics Officer	○	○	
40	IZUMIYAMA	Masafumi	Ship's Doctor	○	○	○
41	SAKUMA	Seizo	Chief Steward	○	○	○
42	YAMADA	Yasutaka	Steward	○	○	○
43	HONDA	Seiji	Steward	○	○	
44	OKAMURA	Shinya	Steward			○
45	SHIKI	Junichi	Steward	○	○	○
46	SAITO	Akihide	Steward	○	○	○
				37	37	37

## 4. Track and station list

### KH-09-5 Leg1-3 (Tokyo-Cape Town)



KH-09-5	Station No.	Location (Latitude)	Location (Longitude)	Depth ( m )	Dates	CTD Hydrocast	Kevlar Hydrocast	GAMOS	Light Intensity	Large Volume	Bathymetric survey	Multiple Coring	Piston Coring	Plankton Sampling	Argo Float	Remarks
	Tokyo	36°N	140°E													
(Leg-1)	ER-1	10°00'N	88°00'E	3430	17 Nov.	○			○	○						GEOSECS-445 GEOSECS-448
	ER-2	8°31'N	86°02'E	3680	18 Nov.	○		○	○	○						
	ER-3	0°00'N	80°00'E	4660	20-22 Nov	○	○	○	○							
	Cochin	9°58'N	76°16'E													
(Leg-2)	ER-4	17°17'N	69°04'E	3500	29 Nov.						○	○	○			
	ER-5	16°45'N	69°00'E	3630	29-30 Nov.	○		○	○	○		○				
	ER-6	14°00'N	69°00'E	4090	01-02 Dec.	○			○	○		○				
	ER-7	10°00'N	68°45'E	4510	03-04 Dec.	○			○	○		○				
	ER-8	4°01'N	69°00'E	4130	05 Dec.	○			○	○		○				
	ER-9	5°16'S	67°54'E	3120	07 Dec.	○			○	○		○				
	ER-10	20°00'S	72°33'E	4340	10-13 Dec.	○	○	○	○	○		○				
	Port Louis	20°S	57°E													
(Leg-3)	ER-11	30°00'S	65°00'E	4660	21-22 Dec.	○				○		○		○	○	GEOSECS-428
	ER-12	37°45'S	57°37'E	5320	23-25 Dec.	○				○		○		○	○	
	ER-13	54°00'S	52°00' E		28 Dec.						○					
	ER-14	62°00'S	40°05'E	5200	29-31 Dec.	○				○		○		○		
	ER-15	65°10'S	33°20'E	3200	01 Jan.						○	○	○	○		
	Cape Town	34°S	18°E													
Total						12	2	3	9	11	3	11	2	4	3*	

( \*The other one Argo float deployment was performed at (44°20'S, 28°53.5'E) as an underway operation, together with XCTD observation, on 5 Jan. 2010.)

# 5. Event log

## 5.1. Leg-1

Date	Time (GMT)	Latitude	Longitude	Depth(m)	Station	Ship logs
91106		545 35 34.483N	139 48.367E	33		CHANGED ENG'S TO T/M
91106		547 35 34.334N	139 48.583E	33		CLEARED TOKYO WEST PASSAGE
91106		659 35 19.709N	139 42.597E	33		ENTERED URAGA SUIDO TRAFFIC ROUTE
91106		738 35 12.534N	139 46.055E	33		CLEARED OUT URAGA SUIDO TRAFFIC ROUTE
91106		741 35 11.953N	139 45.908E	33		SUNSET & PUT ON REGULATION LIGHTS
91106		745 35 10.854N	139 45.525E	33		R/UP ENG'S
91106		800 35 07.262N	139 43.705E	33		S/CO ON 236°
91106		937 34 53.104N	139 18.095E	1259		A/CO TO 217°
91106		1511 34 26.724N	137 43.383E	788		A/CO TO 253°
91106		1719 34 16.057N	137 01.598E	152		A/CO TO 227°
91106		2218 33 23.375N	135 49.505E	515		A/CO TO 262°
91107		400 33 11.923N	134 16.372E	952		COM'CED LIFEBOAT STATION DRILL
91107		415 33 09.830N	134 12.976E	265		FINISHED LIFEBOAT STATION DRILL
91107		812 32 42.874N	133 18.904E	651		SUNSET & PUT ON REGULATION LIGHTS
91107		1400 31 56.651N	131 48.369E	657		A/CO TO 200°
91107		2032 30 20.396N	131 07.612E	1084		A/CO TO 210°
91107		2135 30 06.441N	130 57.504E	415		SUNRISE & TURNED OFF REGULATION LIGHTS
91108		430 28 31.639N	129 54.868E	313		A/CO TO 215°
91108		836 27 37.674N	129 11.924E	696		SUNSET & PUT ON REGULATION LIGHTS
91108		1538 26 05.710N	127 59.209E	534		A/CO TO 230°
91108		2146 25 01.725N	126 36.063E	1740		SUNRISE & TURNED OFF REGULATION LIGHTS
91109		902 23 05.672N	124 03.759E	6327		SUNSET & PUT ON REGULATION LIGHTS
91109		1940 21 17.626N	121 44.966E	5966		A/CO TO 228°
91109		2201 20 53.927N	121 15.278E	5966		SUNRISE & TURNED OFF REGULATION LIGHTS
91110		927 18 46.848N	118 48.522E	5966		SUNSET & PUT ON REGULATION LIGHTS
91110		1200 18 16.678N	118 14.154E	5966		PUT CLOCKS BACK 1H(GMT+0800)
91110		2208 16 21.798N	116 01.672E	5966		A/CO TO 222°
91110		2217 16 20.083N	116 00.150E	5966		SUNRISE & TURNED OFF REGULATION LIGHTS
91111		149 15 37.146N	115 21.522E	5966		P'D SUNK FISHING BOAT
91111		955 13 58.623N	113 46.511E	5966		SUNSET & PUT ON REGULATION LIGHTS
91111		2230 11 28.134N	111 26.513E	5966		SUNRISE & TURNED OFF REGULATION LIGHTS
91112		430 10 17.089N	110 20.585E	5966		S/B ENG'S
91112		600 10 00.795N	110 05.052E	5966		A/CO TO 215°
91112		1018 09 08.802N	109 27.959E	5966		SUNSET & PUT ON REGULATION LIGHTS
91112		1546 07 59.301N	108 40.788E	5966		R/UP ENG'S
91112		2241 06 24.007N	107 33.719E	5966		SUNRISE & TURNED OFF REGULATION LIGHTS
91113		722 04 26.221N	106 10.599E	5966		A/CO TO 231°
91113		1040 03 50.596N	105 28.466E	5966		SUNSET & PUT ON REGULATION LIGHTS
91113		1255 03 27.790N	104 59.987E	5966		A/CO TO 192°
91113		2003 01 31.920N	104 34.343E	5966		A/CO TO 229°
91113		2026 01 27.574N	104 29.587E	5966		S/B ENG'S
91114		531 01 57.039N	102 16.157E	5966		A/CO TO 308°
91114		924 02 37.226N	101 26.135E	5966		A/CO TO 297°
91114		1103 02 48.937N	101 03.054E	5966		SUNSET & PUT ON REGULATION LIGHTS
91114		1216 03 02.807N	100 47.213E	5966		R/UP ENG'S
91114		2100 04 41.465N	099 07.876E	5966		PUT SHIP'S CLOCKS BACK 1H (GMT+7H)
91114		2314 05 06.543N	098 41.014E	5966		SUNRISE & TURNED OFF REGULATION LIGHTS
91115		231 05 42.189N	098 02.954E	5966		A/CO TO 290°
91115		1115 06 29.529N	095 54.848E	5966		SUNSET & PUT ON REGULATION LIGHTS
91115		1500 06 49.651N	095 00.575E	5966		A/CO TO 225°
91115		1800 06 15.578N	094 25.828E	5966		PUT SHIP'S CLOCKS BACK 1H (GMT+6H)
91115		1919 06 00.158N	094 09.732E	5966		A/CO TO 270°
91115		2200 05 59.830N	093 25.195E	5966		A/CO TO 307°
91115		2337 06 15.560N	093 03.873E	5966		SUNRISE & TURNED OFF REGULATION LIGHTS
91116		1135 08 12.880N	090 24.817E	5966		S/B ENG'S
91116		1136 08 12.921N	090 24.763E	5966		SUNSET & PUT ON REGULATION LIGHTS
91116		2347 09 59.832N	088 00.273E	3428		STOPPED ENG'S
91116		2356 09 59.858N	088 00.187E	3426		CHANGED ENG'S TO E/M
91117		9 09 59.966N	088 00.135E	3427	ER-1	CTD-CMS STARTED
91117		16 10 00.003N	088 00.115E	0	ER-1	SUNRISE & TURNED OFF REGULATION LIGHTS
91117		124 10 00.180N	088 00.382E	3430	ER-1	CTD-CMS DEEPEST
91117		241 10 00.509N	088 00.820E	3430	ER-1	CTD-CMS FINISHED

91117	323 10 00.053N	088 00.028	3429 ER-1	LARGE VOLUME SAMPLING STARTED
91117	355 09 59.931N	088 00.224	3430 ER-1	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91117	424 09 59.680N	088 00.447	3435 ER-1	LARGE VOLUME SAMPLING COVER CLOSED 20m
91117	430 09 59.656N	088 00.482	3431 ER-1	LARGE VOLUME SAMPLING COVER CLOSED 10m
91117	432 09 59.647N	088 00.493	3430 ER-1	LARGE VOLUME SAMPLING FINISHED
91117	450 09 59.690N	088 00.552	3430 ER-1	IMF STARTED
91117	503 09 59.814N	088 00.575	3431 ER-1	IMF DEEPEST
91117	516 09 59.836N	088 00.615	3437 ER-1	IMF FINISHED
91117	522 09 59.873N	088 00.637	3434	CHANGED ENG'S TO T/M
91117	600 09 55.700N	087 54.983	3462	R/UP ENG'S
91117	1149 08 58.885N	086 39.426	3633	SUNSET & PUT ON REGULATION LIGHTS
91117	1434 08 31.957N	086 03.235	3678	S/B ENG'S
91117	1452 08 31.006N	086 01.894	3680	CHANGED ENG'S TO E/M
91117	1457 08 31.057N	086 01.879	3679 ER-2	CTD-CMS STARTED
91117	1627 08 31.104N	086 01.560	3676 ER-2	CTD-CMS DEEPEST
91117	1746 08 31.028N	086 01.263	3678 ER-2	CTD-CMS FINISHED
91117	2209 08 31.026N	086 01.999	3679 ER-2	CTD-CMS STARTED
91117	2303 08 31.127N	086 01.806	3677 ER-2	CTD-CMS DEEPEST
91118	8 08 31.270N	086 01.618	3676 ER-2	CTD-CMS FINISHED
91118	8 08 31.270N	086 01.618	3676 ER-2	SUNRISE & TURNED OFF REGULATION LIGHTS
91118	335 08 31.073N	086 01.918	3680 ER-2	CTD-CMS STARTED
91118	410 08 31.179N	086 01.649	3681 ER-2	CTD-CMS DEEPEST
91118	446 08 31.176N	086 01.371	3677 ER-2	CTD-CMS FINISHED
91118	554 08 31.281N	086 01.567	3678 ER-2	IMF SATRTED
91118	607 08 31.348N	086 01.481	3676 ER-2	IMF DEEPEST
91118	619 08 31.373N	086 01.380	3676 ER-2	IMF FINISHED
91118	828 08 31.043N	086 01.922	3675 ER-2	CTD-CMS STARTED
91118	840 08 31.188N	086 01.811	3680 ER-2	CTD-CMS DEEPEST
91118	900 08 31.310N	086 01.587	3674 ER-2	CTD-CMS FINISHED
91118	1033 08 31.236N	086 01.974	3680 ER-2	CTD-CMS STARTED
91118	1047 08 31.461N	086 01.869	3676 ER-2	CTD-CMS DEEPEST
91118	1110 08 31.572N	086 01.763	3674 ER-2	CTD-CMS FINISHED
91118	1153 08 30.998N	086 01.931	3680 ER-2	SUNSET & PUT ON REGULATION LIGHTS
91118	1347 08 31.185N	086 01.985	3677 ER-2	CTD-CMS STARTED
91118	1400 08 31.345N	086 01.875	3681 ER-2	CTD-CMS DEEPEST
91118	1420 08 31.490N	086 01.751	3679 ER-2	CTD-CMS FINISHED
91118	1456 08 31.139N	086 02.013	3681 ER-2	LARGE VOLUME SAMPLING STARTED
91118	1520 08 31.664N	086 01.792	3675 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 800m
91118	1529 08 31.768N	086 01.708	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 600m
91118	1535 08 31.823N	086 01.659	3676 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 400m
91118	1539 08 31.872N	086 01.622	3681 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 300m
91118	1551 08 32.060N	086 01.519	3672 ER-2	LARGE VOLUME SAMPLING FINISHED
91118	1633 08 31.068N	086 02.103	3681 ER-2	LARGE VOLUME SAMPLING STARTED
91118	1643 08 31.242N	086 02.049	3680 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 200m
91118	1647 08 31.304N	086 02.026	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 150m
91118	1651 08 31.366N	086 02.001	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 100m
91118	1655 08 31.421N	086 01.976	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 80m
91118	1702 08 31.563N	086 01.917	3676 ER-2	LARGE VOLUME SAMPLING FINISHED
91118	1734 08 31.009N	086 01.956	3681 ER-2	LARGE VOLUME SAMPLING STARTED
91118	1739 08 31.077N	086 01.930	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 60m
91118	1743 08 31.158N	086 01.898	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 40m
91118	1747 08 31.245N	086 01.867	3681 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 20m
91118	1750 08 31.315N	086 01.842	3679 ER-2	LARGE VOLUME SAMPLING COVER CLOSED 10m
91118	1754 08 31.402N	086 01.812	3673 ER-2	LARGE VOLUME SAMPLING FINISHED
91118	1820 08 31.093N	086 01.963	3678 ER-2	GAMOS STARTED
91118	1843 08 31.260N	086 01.851	3678 ER-2	GAMOS DEEPEST
91118	1917 08 31.295N	086 01.698	3676 ER-2	GAMOS FINISHED
91118	1929 08 31.453N	086 01.640	3674	CHANGED ENG'S TO T/M
91118	1929 08 31.453N	086 01.640	3676	SLOW AHEAD ENG'S
91118	1933 08 31.335N	086 01.514	3678	S/CO ON 199°
91118	1954 08 27.279N	086 00.328	3685	R/UP ENG'S
91119	9 07 22.956N	085 38.566	3781	SUNRISE & TURNED OFF REGULATION LIGHTS
91119	1000 04 48.293N	084 46.246	4082	A/CO TO 224°
91119	1205 04 23.327N	084 22.762	4133	SUNSET & PUT ON REGULATION LIGHTS
91120	16 02 15.588N	082 11.095	4369	SUNRISE & TURNED OFF REGULATION LIGHTS
91120	1228 00 06.786N	080 06.805	4645	SUNSET & PUT ON REGULATION LIGHTS

91120	1257 00 01.184N	080 02.014I	4658	S/B ENG'S USED HELM VAR'LY
91120	1312 00 00.090S	080 00.404I	4657	STOPPED ENG'S
91120	1322 00 00.029S	080 00.565I	4655	CHANGED ENG'S TO E/M
91120	1329 00 00.027N	080 00.733I	4665 ER-3	KEVLAR SAMPLING STARTED
91120	1407 00 00.060N	080 00.860I	4660 ER-3	KEVLAR SAMPLING SENT MASSANGER
91120	1427 00 00.038S	080 00.893I	4658 ER-3	COM'CED HEAVING KEVLAR ROPE(SAMPLING BOTTLE)
91120	1455 00 00.142S	080 00.886I	4664 ER-3	KEVLAR SAMPLING FINISHED
91120	1521 00 00.149N	080 00.039I	4664 ER-3	KEVLAR SAMPLING STARTED
91120	1556 00 00.067N	080 00.111I	4660 ER-3	KEVLAR SAMPLING SENT MESSANGER
91120	1616 00 00.011S	080 00.127I	4660 ER-3	COM'CED HEAVING KEVLAR ROPE(SAMPLING BOTTLE)
91120	1643 00 00.134S	080 00.139I	4660 ER-3	KEVLAR SAMPLING FINISHED
91120	1709 00 00.018S	080 00.046I	4661 ER-3	CTD-CMS STARTED
91120	1841 00 00.348S	080 00.384I	4659 ER-3	CTD-CMS DEEPEST
91120	2013 00 00.533S	080 00.774I	4655 ER-3	CTD-CMS FINISHED
91121	3 00 00.073S	080 00.075I	4665 ER-3	CTD-CMS STARTED
91121	21 00 00.093S	080 00.209I	4659 ER-3	SUNRISE & TURNED OFF REGULATION LIGHTS
91121	105 00 00.224S	080 00.443I	4661 ER-3	CTD-CMS DEEPEST
91121	224 00 00.381S	080 00.755I	4660 ER-3	CTD-CMS FINISHED
91121	552 00 00.172S	080 00.342I	4659 ER-3	IMF STARTED
91121	607 00 00.264S	080 00.614I	4660 ER-3	IMF DEEPEST
91121	620 00 00.343S	080 00.809I	4660 ER-3	IMF SFINISHED
91121	643 00 00.054S	080 00.117I	4657 ER-3	CTD-CMS STARTED
91121	717 00 00.269S	080 00.335I	4657 ER-3	CTD-CMS DEEPEST
91121	756 00 00.400S	080 00.484I	4663 ER-3	CTD-CMS FINISHED
91121	1159 00 00.024S	080 00.060I	4660 ER-3	CTD-CMS STARTED
91121	1228 00 00.160S	080 00.175I	4662 ER-3	CTD-CMS DEEPEST
91121	1229 00 00.166S	080 00.179I	4660 ER-3	SUNSET & PUT ON REGULATION LIGHTS
91121	1302 00 00.380S	080 00.293I	4660 ER-3	CTD-CMS FINISHED
91121	1701 00 00.105S	080 00.036I	4661 ER-3	CTD-CMS STARTED
91121	1758 00 00.584S	080 00.571I	4660 ER-3	CTD-CMS FINISHED
91121	2127 00 00.051S	080 00.036I	4658 ER-3	CTD-CMS STARTED
91121	2140 00 00.035S	080 00.192I	4659 ER-3	CTD-CMS DEEPEST
91121	2202 00 00.036S	080 00.349I	4663 ER-3	CTD-CMS FINISHED
91122	22 00 00.008S	080 00.031I	4663 ER-3	SUNRISE & TURNED OFF REGULATION LIGHTS
91122	154 00 00.090S	080 00.053I	4660 ER-3	CTD-CMS STARTED
91122	206 00 00.131S	080 00.169I	4658 ER-3	CTD-CMS DEEPEST
91122	223 00 00.219S	080 00.472I	4662 ER-3	CTD-CMS FINISHED
91122	304 00 00.109S	080 00.841I	4665 ER-3	GAMOS STARTED
91122	327 00 00.234S	080 01.077I	4660 ER-3	GAMOS DEEPEST
91122	400 00 00.463S	080 01.335I	4659 ER-3	GAMOS FINISHED
91122	409 00 00.477S	080 01.506I	4659 ER-3	NO.2 WINCH FREE FALL STARTED
91122	530 00 00.965S	080 02.163I	4661 ER-3	FREE FALL DEEPEST(W.O.=4400m)
91122	708 00 01.571S	080 02.631I	4657 ER-3	NO.2 WINCH FREE FALL FINISHED
91122	716 00 01.604S	080 02.782I	4657	CLUTCH TRIAL START
91122	818 00 01.211S	080 04.548I	4660	CLUTCH TRIAL FINISHED
91122	820 00 01.194S	080 04.601I	4655	CHANGED ENG'S TO T/M
91122	820 00 01.194S	080 04.603I	4657	SLOW AHEAD ENG'S
91122	822 00 01.142S	080 04.632I	4655	S/CO ON 328°
91122	840 00 01.753N	080 02.686I	4654	R/UP ENG'S
91122	1230 00 51.972N	079 28.655I	4648	SUNSET & PUT ON REGULATION LIGHTS
91122	1500 01 25.655N	079 06.882I	4530	PUT SHIP'S CLOCKS BACK 30MIN (INDIAN LT)
91123	32 03 34.856N	077 45.832I	3380	SUNRISE & TURNED OFF REGULATION LIGHTS
91123	547 04 46.808N	077 00.829I	3100	ENTERD INDIA EEZ
91123	552 04 47.928N	077 00.130I	3100	A/CO TO 349°
91123	1234 06 33.244N	076 38.747I	3100	SUNSET & PUT ON REGULATION LIGHTS
91123	1430 07 05.076N	076 32.314I	3100	S/B ENG'S
91123	2158 08 58.324N	076 09.390I	3100	A/CO TO 000°
91124	52 09 43.748N	076 08.614I	3100	SUNRISE & TURNED OFF REGULATION LIGHTS
91124	153 09 58.402N	076 07.269I	3100	CHANGED ENG'S TO S/M
91124	157 09 58.493N	076 07.450I	3100	STOPPED ENG'S
91124	238 09 57.891N	076 09.861I	3100	PILOT CAME ON BOARD

## 5.2. Leg-2

Date	Time (GMT)	Latitude	Longitude	Depth(m)	Station	Ship logs
91127	640 09	57.945N	076 15.651E	3100		
91127	1015 09	58.441N	076 08.133E	3100		R/UP ENG'S
91127	1235 10	27.227N	075 41.640E	3100		SUNSET & PUT ON REGULATION LIGHTS
91128	112 13	02.009N	073 22.859E	3100		SUNRISE & TURNED OFF REGULATION LIGHTS
91128	559 13	59.665N	072 30.397E	3100		A/CO TO 311°
91128	730 14	15.867N	072 11.422E	3100		COM'CED LIFEBOAT STATION DRILL
91128	745 14	18.586N	072 08.286E	3100		FINISHED LIFEBOAT STATION DRILL
91128	1243 15	13.549N	071 04.513E	3100		SUNSET & PUT ON REGULATION LIGHTS
91128	1530 15	44.914N	070 27.792E	3100		PUT SHIP'S CLOCKS ABACK 30min
91128	1812 16	15.195N	069 52.430E	3100		CLEARED OUT INDIAN EEZ
91128	1932 16	29.879N	069 35.695E	3630		A/CO TO 338°
91128	1959 16	36.594N	069 32.877E	3613		A/CO TO 325°
91128	2245 17	13.591N	069 06.014E	3520		S/B ENG'S USED ENG'S VAR'LY
91128	2245 17	13.602N	069 06.007E	3520		USED HELM VAR'LY
91128	2248 17	14.291N	069 05.532E	3517		SBP(3.5KHZ) SURVEY STARTED
91129	136 16	57.358N	069 07.064E	3590		SUNRISE & TURNED OFF REGULATION LIGHTS
91129	255 17	15.736N	069 03.832E	3128		SBP(3.5KHZ) SURVEY FINISHED
91129	305 17	17.043N	069 03.130E	3491		STOPPED ENG'S
91129	315 17	17.060N	069 03.298E	3491		CHANGED ENG'S TO E/M
91129	319 17	17.048N	069 03.328E	3492	ER-4	MULTIPLE CORER STARTED
91129	429 17	16.881N	069 03.700E	3498	ER-4	MULTIPLE CORER HIT BOTTOM
91129	432 17	16.871N	069 03.715E	3499	ER-4	MULTIPLE CORER LEFT BOTTOM
91129	529 17	16.613N	069 03.921E	3499	ER-4	MULTIPLE CORER FINISHED
91129	558 17	17.387N	069 03.233E	3495	ER-4	PISTON CORER STARTED
91129	718 17	17.074N	069 03.407E	3496	ER-4	PISTON CORER HIT BOTTOM
91129	720 17	17.071N	069 03.410E	3499	ER-4	PISTON CORER LEFT BOTTOM
91129	828 17	16.477N	069 03.510E	3496	ER-4	PISTON CORER FINISHED
91129	858 17	16.158N	069 03.545E	3463		CHANGED ENG'S TO T/M SLOW AHEAD ENG'S
91129	902 17	16.035N	069 03.446E	3340		S/CO ON 186°
91129	918 17	12.728N	069 03.184E	2740		R/UP ENG'S
91129	1050 16	46.913N	069 00.121E	3615		S/B ENG'S USED ENG'S VAR'LY
91129	1050 16	46.899N	069 00.119E	3615		USED HELM VAR'LY
91129	1102 16	44.782N	068 59.970E	3625		STOPPED ENG'S
91129	1109 16	44.691N	068 59.969E	3635		CHANGED ENG'S TO E/M
91129	1116 16	44.599N	068 59.937E	3630	ER-5	CTD-CMS STARTED
91129	1226 16	44.583N	068 59.728E	3623	ER-5	CTD-CMS DEEPEST
91129	1250 16	44.661N	068 59.615E	3623	ER-5	SUNSET & PUT ON REGULATION LIGHTS
91129	1342 16	44.710N	068 59.386E	3622	ER-5	CTD-CMS FINISHED
91129	1410 16	45.028N	068 59.913E	3628	ER-5	LARGE VOLUME SAMPLING STARTED
91129	1447 16	45.242N	068 59.860E	3628	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91129	1501 16	45.372N	068 59.849E	3625	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91129	1509 16	45.449N	068 59.843E	3624	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 1250m
91129	1518 16	45.542N	068 59.837E	3623	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91129	1540 16	45.686N	068 59.782E	3623	ER-5	LARGE VOLUME SAMPLING FINISHED
91129	1619 16	44.924N	068 59.962E	3627	ER-5	LARGE VOLUME SAMPLING STARTED
91129	1642 16	45.048N	068 59.899E	3626	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 800m
91129	1647 16	45.080N	068 59.885E	3627	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 600m
91129	1653 16	45.105N	068 59.864E	3633	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 400m
91129	1657 16	45.118N	068 59.848E	3629	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 300m
91129	1707 16	45.171N	068 59.809E	3626	ER-5	LARGE VOLUME SAMPLING FINISHED
91129	1726 16	44.862N	069 00.006E	3627	ER-5	CTD-CMS STARTED
91129	1827 16	44.747N	068 59.462E	3625	ER-5	CTD-CMS DEEPEST
91129	1932 16	44.812N	068 58.958E	3623	ER-5	CTD-CMS FINISHED
91129	1956 16	45.034N	068 59.899E	3625	ER-5	LARGE VOLUME SAMPLING STARTED
91129	2006 16	45.047N	068 59.811E	3624	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 200m
91129	2011 16	45.075N	068 59.767E	3628	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 150m
91129	2015 16	45.104N	068 59.732E	3624	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 100m
91129	2018 16	45.126N	068 59.708E	3623	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 80m
91129	2025 16	45.141N	068 59.635E	3624	ER-5	LARGE VOLUME SAMPLING FINISHED
91129	2059 16	45.086N	068 59.623E	3625	ER-5	LARGE VOLUME SAMPLING STARTED
91129	2104 16	45.059N	068 59.587E	3625	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 60m
91129	2108 16	45.038N	068 59.554E	3625	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 40m
91129	2111 16	45.019N	068 59.525E	3625	ER-5	LARGE VOLUME SAMPLING COVER CLOSED 20m

91129	2114 16 44.999N068 59.492I	3622 ER-5	LARGE VOLUME SAMPLING COVER CLOSED 10m
91129	2117 16 44.983N068 59.459I	3624 ER-5	LARGE VOLUME SAMPLING FINISHED
91129	2201 16 45.055N069 00.031I	3625 ER-5	CTD-CMS STARTED
91129	2238 16 45.074N068 59.708I	3624 ER-5	CTD-CMS DEEPEST
91129	2323 16 44.898N068 59.284I	3621 ER-5	CTD-CMS FINISHED
91129	2345 16 45.015N068 59.998I	3625 ER-5	MULTIPLE CORER STARTED
91130	52 16 45.011N069 00.023I	3627 ER-5	MULTIPLE CORER HIT BOTTOM
91130	53 16 45.007N069 00.019I	3626 ER-5	MULTIPLE CORER LEFT BOTTOM
91130	136 16 45.068N069 00.048I	3625 ER-5	SUNRISE & TURNED OFF REGULATION LIGHTS
91130	148 16 45.033N069 00.021I	3626 ER-5	MULTIPLE CORER FINISHED
91130	203 16 45.029N068 59.995I	3626 ER-5	CTD-CMS STARTED
91130	222 16 44.970N068 59.849I	3626 ER-5	CTD-CMS DEEPEST
91130	245 16 44.874N068 59.688I	3624 ER-5	CTD-CMS FINISHED
91130	441 16 44.943N068 59.882I	3628 ER-5	CTD-CMS STARTED
91130	458 16 44.905N068 59.708I	3627 ER-5	CTD-CMS DEEPEST
91130	520 16 44.831N068 59.425I	3623 ER-5	CTD-CMS FINISHED
91130	525 16 44.796N068 59.367I	3623 ER-5	IMF STARTED
91130	535 16 44.788N068 59.211I	3623 ER-5	IMF DEEPEST
91130	544 16 44.782N068 59.097I	3624 ER-5	IMF FINISHED
91130	701 16 45.062N068 59.843I	3625 ER-5	CTD-CMS STARTED
91130	714 16 45.063N068 59.653I	3625 ER-5	CTD-CMS DEEPEST
91130	734 16 45.034N068 59.380I	3625 ER-5	CTD-CMS FINISHED
91130	859 16 44.864N069 00.043I	3626 ER-5	CTD-CMS STARTED
91130	912 16 44.835N068 59.854I	3625 ER-5	CTD-CMS DEEPEST
91130	932 16 44.779N068 59.546I	3623 ER-5	CTD-CMS FINISHED
91130	1009 16 45.010N068 59.905I	3623 ER-5	GAMOS STARTED
91130	1033 16 44.990N068 59.655I	3624 ER-5	GAMOS DEEPEST
91130	1106 16 44.925N068 59.323I	3623 ER-5	GAMOS FINISHED
91130	1118 16 44.877N068 59.200I	3622	CHANGED ENG'S TO T/M
91130	1118 16 44.876N068 59.200I	3623	SLOW AHEAD ENG'S
91130	1122 16 44.782N068 59.133I	3620	S/CO ON 180°
91130	1250 16 23.899N068 59.873I	3671	SUNSET & PUT ON REGULATION LIGHTS
91130	2230 14 00.915N068 59.901I	4090	USED HELM VAR'LY
91130	2240 14 00.042N068 59.991I	4092	STOPPED ENG'S
91130	2245 14 00.003N068 59.980I	4095	CHANGED ENG'S TO E/M
91130	2258 13 59.896N068 59.875I	4091 ER-6	CTD-CMS STARTED
91201	16 14 00.124N068 59.460I	4094 ER-6	CTD-CMS DEEPEST
91201	136 14 00.345N068 59.051I	4093 ER-6	SUNRISE & TURNED OFF REGULATION LIGHTS
91201	136 14 00.345N068 59.048I	4094 ER-6	CTD-CMS FINISHED
91201	204 13 59.991N069 00.047I	4090 ER-6	LARGE VOLUME SAMPLING STARTED
91201	241 14 00.153N069 00.145I	4094 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91201	252 14 00.220N069 00.185I	4092 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91201	302 14 00.275N069 00.221I	4092 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91201	311 14 00.340N069 00.253I	4093 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 600m
91201	327 14 00.458N069 00.329I	4094 ER-6	LARGE VOLUME SAMPLING FINISHED
91201	354 13 59.891N068 59.969I	4094 ER-6	CTD-CMS STARTED
91201	524 14 00.084N068 59.401I	4093 ER-6	CTD-CMS DEEPEST
91201	647 14 00.257N068 59.012I	4094 ER-6	CTD-CMS FINISHED
91201	714 14 00.071N069 00.030I	4091 ER-6	LARGE VOLUME SAMPLING STARTED
91201	724 14 00.046N068 59.940I	4090 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 200m
91201	728 14 00.056N068 59.917I	4091 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 100m
91201	732 14 00.069N068 59.893I	4092 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 50m
91201	736 14 00.082N068 59.875I	4094 ER-6	LARGE VOLUME SAMPLING COVER CLOSED 10m
91201	740 14 00.075N068 59.851I	4089 ER-6	LARGE VOLUME SAMPLING FINISHED
91201	756 13 59.878N068 59.702I	4090 ER-6	IMF STARTED
91201	807 13 59.786N068 59.645I	4093 ER-6	IMF DEEPEST
91201	817 13 59.776N068 59.622I	4090 ER-6	IMF FINISHED
91201	852 14 00.068N068 59.997I	4091 ER-6	CTD-CMS STARTED
91201	954 14 00.130N068 59.667I	4092 ER-6	CTD-CMS DEEPEST
91201	1056 14 00.302N068 59.323I	4092 ER-6	CTD-CMS FINISHED
91201	1119 14 00.025N069 00.051I	4095 ER-6	MULTIPLE CORER STARTED
91201	1236 14 00.013N068 59.970I	4092 ER-6	MULTIPLE CORER HIT BOTTOM
91201	1238 14 00.012N068 59.963I	4092 ER-6	MULTIPLE CORER LEFT BOTTOM
91201	1255 14 00.005N068 59.975I	4092 ER-6	SUNSET & PUT ON REGULATION LIGHTS
91201	1339 14 00.055N068 59.982I	4092 ER-6	MULTIPLE CORER FINISHED
91201	1352 13 59.960N068 59.892I	4093 ER-6	CTD-CMS STARTED



91201	1424 14 00.032N068 59.675I	4096 ER-6	CTD-CMS DEEPEST
91201	1500 14 00.203N068 59.501I	4092 ER-6	CTD-CMS FINISHED
91201	1657 13 59.979N068 59.891I	4090 ER-6	CTD-CMS STARTED
91201	1727 14 00.019N068 59.633I	4094 ER-6	CTD-CMS DEEPEST
91201	1755 14 00.143N068 59.463I	4090 ER-6	CTD-CMS FINISHED
91201	1918 13 59.982N069 00.012I	4090 ER-6	CTD-CMS STARTED
91201	1947 13 59.960N068 59.941I	4092 ER-6	CTD-CMS DEEPEST
91201	2008 13 59.929N068 59.899I	4090 ER-6	CTD-CMS FINISHED
91201	2148 14 00.058N068 59.977I	4090 ER-6	CTD-CMS STARTED
91201	2201 14 00.109N068 59.995I	4090 ER-6	CTD-CMS DEEPEST
91201	2217 14 00.184N069 00.038I	4087 ER-6	CTD-CMS FINISHED
91201	2330 14 00.018N068 59.972I	4090 ER-6	CTD-CMS STARTED
91201	2347 14 00.134N068 59.909I	4090 ER-6	CTD-CMS DEEPEST
91202	4 14 00.244N068 59.835I	4090 ER-6	CTD-CMS FINISHED
91202	136 14 00.011N068 59.995I	4091 ER-6	SUNRISE & TURNED OFF REGULATION LIGHTS
91202	146 13 59.991N069 00.038I	4091 ER-6	CTD-CMS STARTED
91202	200 14 00.084N069 00.022I	4091 ER-6	CTD-CMS DEEPEST
91202	221 14 00.098N068 59.927I	4093 ER-6	CTD-CMS FINISHED
91202	337 13 59.632N068 59.630I	4094 ER-6	COM'CED ADJUSTMENT OF No.2 WINCH
91202	452 13 59.680N068 59.215I	4093 ER-6	FINISHED ADJUSTMENT OF No.2 WINCH
91202	502 13 59.641N068 59.120I	4093	CHANGED ENG'S TO T/M
91202	532 13 53.723N068 58.989I	4097	S/CO ON 187°
91202	1258 12 10.559N068 46.146I	4278	SUNSET & PUT ON REGULATION LIGHTS
91202	1643 11 19.447N068 40.035I	4353	A/CO TO 176°
91202	2219 10 02.172N068 44.919I	4509	USED HELM VAR'LY
91202	2233 10 00.106N068 44.993I	4503	STOPPED ENG'S
91202	2238 10 00.027N068 45.013I	4509	CHANGED ENG'S TO E/M
91202	2254 09 59.873N068 44.964I	4514 ER-7	CTD-CMS STARTED
91203	24 09 59.891N068 44.798I	4511 ER-7	CTD-CMS DEEPEST
91203	127 09 59.815N068 44.622I	4514 ER-7	SUNRISE & TURNED OFF REGULATION LIGHTS
91203	154 09 59.876N068 44.572I	4513 ER-7	CTD-CMS FINISHED
91203	214 10 00.048N068 45.050I	4509 ER-7	LARGE VOLUME SAMPLING STARTED
91203	247 10 00.226N068 45.188I	4511 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91203	258 10 00.287N068 45.226I	4507 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91203	304 10 00.314N068 45.255I	4510 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 1250m
91203	310 10 00.351N068 45.275I	4510 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91203	331 10 00.435N068 45.341I	4510 ER-7	LARGE VOLUME SAMPLING FINISHED
91203	355 09 59.936N068 44.975I	4516 ER-7	CTD-CMS STARTED
91203	511 10 00.307N068 45.175I	4511 ER-7	CTD-CMS DEEPEST
91203	640 10 00.495N068 45.389I	4512 ER-7	CTD-CMS FINISHED
91203	647 10 00.490N068 45.304I	4516 ER-7	IMF STARTED
91203	656 10 00.495N068 45.180I	4512 ER-7	IMF DEEPEST
91203	706 10 00.517N068 45.074I	4509 ER-7	IMF FINISHED
91203	724 09 59.891N068 44.984I	4510 ER-7	LARGE VOLUME SAMPLING STARTED
91203	744 09 59.903N068 44.911I	4510 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 800m
91203	750 09 59.926N068 44.920I	4509 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 600m
91203	756 09 59.943N068 44.925I	4509 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 400m
91203	800 09 59.956N068 44.927I	4508 ER-7	LARGE VOLUME SAMPLING FINISHED 300m
91203	812 10 00.010N068 44.934I	4518 ER-7	LARGE VOLUME SAMPLING FINISHED
91203	830 10 00.006N068 44.881I	4510 ER-7	CTD-CMS STARTED
91203	932 10 00.111N068 44.894I	4508 ER-7	CTD-CMS DEEPEST
91203	1041 10 00.197N068 45.041I	4513 ER-7	CTD-CMS FINISHED
91203	1045 10 00.206N068 45.058I	4510 ER-7	LARGE VOLUME SAMPLING STARTED
91203	1053 10 00.230N068 45.092I	4507 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 200m
91203	1057 10 00.237N068 45.103I	4508 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 150m
91203	1102 10 00.251N068 45.123I	4511 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 100m
91203	1103 10 00.255N068 45.126I	4508 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 80m
91203	1108 10 00.267N068 45.142I	4510 ER-7	LARGE VOLUME SAMPLING FINISHED
91203	1136 10 00.037N068 44.962I	4507 ER-7	LARGE VOLUME SAMPLING STARTED
91203	1141 10 00.036N068 44.953I	4508 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 60m
91203	1144 10 00.042N068 44.953I	4507 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 40m
91203	1148 10 00.057N068 44.962I	4509 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 20m
91203	1150 10 00.066N068 44.968I	4510 ER-7	LARGE VOLUME SAMPLING COVER CLOSED 10m
91203	1152 10 00.072N068 44.972I	4505 ER-7	LARGE VOLUME SAMPLING FINISHED
91203	1211 09 59.981N068 44.917I	4509 ER-7	CTD-CMS STARTED
91203	1300 10 00.091N068 44.663I	4510 ER-7	CTD-CMS DEEPEST

91203	1302 10 00.091N068 44.649I	4511 ER-7	SUNSET & PUT ON REGULATION LIGHTS
91203	1347 10 00.321N068 44.578I	4507 ER-7	CTD-CMS FINISHED
91203	1407 09 59.871N068 44.955I	4509 ER-7	MULTIPLE CORER STARTED
91203	1530 10 00.035N068 45.031I	4510 ER-7	MULTIPLE CORER HIT BOTTOM
91203	1532 10 00.035N068 45.026I	4509 ER-7	MULTIPLE CORER LEFT BOTTOM
91203	1643 10 00.087N068 45.514I	4509 ER-7	MULTIPLE CORER FINISHED
91203	1710 10 00.070N068 44.906I	4509 ER-7	CTD-CMS STARTED
91203	1736 10 00.211N068 44.778I	4507 ER-7	CTD-CMS DEEPEST
91203	1808 10 00.427N068 44.710I	4511 ER-7	CTD-CMS FINISHED
91203	1946 10 00.040N068 45.058I	4510 ER-7	CTD-CMS STARTED
91203	2003 10 00.103N068 45.120I	4508 ER-7	CTD-CMS DEEPEST
91203	2027 10 00.230N068 45.123I	4509 ER-7	CTD-CMS FINISHED
91203	2143 10 00.056N068 44.950I	4511 ER-7	CTD-CMS STARTED
91203	2155 10 00.116N068 45.004I	4510 ER-7	CTD-CMS DEEPEST
91203	2213 10 00.189N068 45.030I	4514 ER-7	CTD-CMS FINISHED
91203	2346 10 00.027N068 44.977I	4509 ER-7	CTD-CMS STARTED
91203	2359 10 00.046N068 44.995I	4508 ER-7	CTD-CMS DEEPEST
91204	16 10 00.066N068 45.047I	4510 ER-7	CTD-CMS FINISHED
91204	127 10 00.048N068 45.109I	4509 ER-7	SUNRISE & TURNED OFF REGULATION LIGHTS
91204	136 10 00.030N068 45.120I	4507 ER-7	CTD-CMS STARTED
91204	148 10 00.017N068 45.109I	4510 ER-7	CTD-CMS DEEPEST
91204	205 10 00.077N068 45.053I	4509 ER-7	CTD-CMS FINISHED
91204	219 10 00.066N068 45.049I	4520	CHANGED ENG'S TO T/M
91204	225 09 59.973N068 44.972I	4510	S/CO ON 166°
91204	241 09 56.893N068 45.569I	4513	R/UP ENG'S
91204	613 09 00.781N068 59.910I	4586	A/CO TO 180°
91204	1307 07 07.845N069 00.154I	4440	SUNSET & PUT ON REGULATION LIGHTS
91205	41 04 02.571N069 00.127I	3637	S/B ENG'S
91205	55 04 00.608N069 00.121I	4042	STOPPED ENG'S
91205	101 04 00.664N069 00.138I	4046	CHANGED ENG'S TO E/M
91205	103 04 00.679N069 00.152I	4034 ER-8	CTD-CMS STARTED
91205	116 04 00.691N069 00.225I	4163 ER-8	SUNRISE & TURNED OFF REGULATION LIGHTS
91205	230 04 00.833N069 00.425I	5 ER-8	CTD-CMS DEEPEST
91205	352 04 00.828N069 00.430I	4126 ER-8	CTD-CMS FINISHED
91205	408 04 00.843N069 00.406I	4129 ER-8	LARGE VOLUME SAMPLING STARTED
91205	445 04 00.692N069 00.379I	4151 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91205	454 04 00.713N069 00.357I	4159 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91205	504 04 00.731N069 00.322I	4156 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91205	512 04 00.744N069 00.279I	4168 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 500m
91205	524 04 00.737N069 00.214I	4168 ER-8	LARGE VOLUME SAMPLING FINISHED
91205	611 04 00.681N068 59.759I	4177 ER-8	LARGE VOLUME SAMPLING STARTED
91205	619 04 00.630N068 59.698I	4178 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 200m
91205	624 04 00.615N068 59.661I	4179 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 100m
91205	629 04 00.608N068 59.622I	4179 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 50m
91205	633 04 00.611N068 59.591I	4183 ER-8	LARGE VOLUME SAMPLING COVER CLOSED 10m
91205	638 04 00.623N068 59.553I	4182 ER-8	LARGE VOLUME SAMPLING FINISHED
91205	641 04 00.633N068 59.530I	4181 ER-8	IMF STARTED
91205	651 04 00.656N068 59.459I	4179 ER-8	IMF DEEPEST
91205	701 04 00.693N068 59.390I	4182 ER-8	IMF FINISHED
91205	720 04 00.566N069 00.130I	4173 ER-8	CTD-CMS STARTED
91205	748 04 00.525N069 00.016I	4178 ER-8	CTD-CMS DEEPEST
91205	823 04 00.493N068 59.968I	4181 ER-8	CTD-CMS FINISHED
91205	838 04 00.466N068 59.960I	4178 ER-8	MULTIPLE CORER STARTED
91205	956 03 59.999N069 00.738I	4162 ER-8	MULTIPLE CORER HIT BOTTOM
91205	959 04 00.011N069 00.741I	4184 ER-8	MULTIPLE CORER LEFT BOTTOM
91205	1103 04 00.170N069 00.868I	4001 ER-8	MULTIPLE CORER FINISHED
91205	1127 04 00.753N068 59.872I	4050 ER-8	CTD-CMS STARTED
91205	1141 04 00.926N068 59.813I	4053 ER-8	CTD-CMS DEEPEST
91205	1202 04 00.982N068 59.645I	4055 ER-8	CTD-CMS FINISHED
91205	1215 04 01.033N068 59.623I	4056	CHANGED ENG'S TO T/M
91205	1221 04 01.024N068 59.723I	4056	S/CO ON 180°
91205	1233 03 58.946N068 59.690I	4008	R/UP ENG'S
91205	1312 03 48.337N068 59.925I	3997	SUNSET & PUT ON REGULATION LIGHTS
91206	112 00 34.236N069 00.324I	4053	SUNRISE & TURNED OFF REGULATION LIGHTS
91206	144 00 25.420N069 00.328I	3420	S/B ENG'S
91206	156 00 23.636N069 00.501I	3467	SURFACE WATER SAMPLING STARTED

91206	207 00 23.376N 069 00.836I	3513	SURFACE WATER SAMPLING FINISHED
91206	224 00 20.926N 069 00.582I	3628	R/UP ENG'S
91206	340 00 00.033S 069 00.217I	3894	PASSED THE EQUATOR SOUTHWARD IN LONG 069-00.2E
91206	1245 02 27.855S 069 00.213I	3485	S/B ENG'S
91206	1256 02 29.662S 069 00.324I	3612	SURFACE WATER SAMPLING STARTED
91206	1308 02 29.852S 069 00.529I	3573	SURFACE WATER SAMPLING FINISHED
91206	1323 02 31.820S 069 00.336I	3504	SUNSET & PUT ON REGULATION LIGHTS
91206	1326 02 32.739S 069 00.229I	3590	R/UP ENG'S
91206	1505 02 59.530S 069 00.143I	3242	A/CO TO 206°
91207	30 05 14.073S 067 55.198I	3273	S/B ENG'S
91207	42 05 16.001S 067 54.186I	3078	STOPPED ENG'S
91207	50 05 16.071S 067 54.164I	3022	CHANGED ENG'S TO E/M
91207	53 05 16.064S 067 54.171I	3029 ER-9	CTD-CMS STARTED
91207	104 05 16.036S 067 54.219I	3066 ER-9	SUNRISE & TURNED OFF REGULATION LIGHTS
91207	204 05 16.017S 067 54.260I	3125 ER-9	CTD-CMS DEEPEST
91207	307 05 16.005S 067 54.333I	3177 ER-9	CTD-CMS FINISHED
91207	324 05 15.901S 067 54.356I	3216 ER-9	LARGE VOLUME SAMPLING STARTED
91207	403 05 15.958S 067 54.503I	3274 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91207	411 05 16.005S 067 54.550I	6 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91207	420 05 16.061S 067 54.600I	3328 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91207	429 05 16.107S 067 54.646I	3384 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 600m
91207	443 05 16.214S 067 54.730I	3463 ER-9	LARGE VOLUME SAMPLING FINISHED
91207	535 05 15.942S 067 54.261I	3141 ER-9	LARGE VOLUME SAMPLING STARTED
91207	545 05 15.977S 067 54.324I	3174 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 200m
91207	549 05 15.994S 067 54.350I	6 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 100m
91207	553 05 16.006S 067 54.367I	6 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 50m
91207	557 05 16.028S 067 54.389I	3211 ER-9	LARGE VOLUME SAMPLING COVER CLOSED 10m
91207	601 05 16.054S 067 54.414I	3213 ER-9	LARGE VOLUME SAMPLING FINISHED
91207	605 05 16.074S 067 54.440I	6 ER-9	IMF STARTED
91207	615 05 16.108S 067 54.501I	3303 ER-9	IMF DEEPEST
91207	624 05 16.064S 067 54.529I	3279 ER-9	IMF FINISHED
91207	630 05 16.023S 067 54.546I	3419 ER-9	CTD-CMS STARTED
91207	657 05 15.901S 067 54.610I	6 ER-9	CTD-CMS DEEPEST
91207	730 05 15.847S 067 54.763I	3442 ER-9	CTD-CMS FINISHED
91207	741 05 15.770S 067 54.796I	3441 ER-9	MULTIPLE CORER STARTED
91207	848 05 15.991S 067 54.538I	3282 ER-9	MULTIPLE CORER HIT BOTTOM
91207	851 05 15.985S 067 54.545I	3275 ER-9	MULTIPLE CORER LEFT BOTTOM
91207	943 05 15.846S 067 55.007I	3460 ER-9	MULTIPLE CORER FINISHED
91207	1013 05 16.085S 067 54.194I	3053 ER-9	CTD-CMS STARTED
91207	1026 05 16.002S 067 54.261I	3132 ER-9	CTD-CMS DEEPEST
91207	1050 05 15.849S 067 54.357I	6 ER-9	CTD-CMS FINISHED
91207	1104 05 15.698S 067 54.362I	3205	CHANGED ENG'S TO T/M SLOW AHEAD ENG'S
91207	1124 05 18.540S 067 53.965I	6	R/UP ENG'S
91207	1333 05 52.774S 067 49.774I	3397	SUNSET & PUT ON REGULATION LIGHTS
91207	1515 06 20.059S 067 46.636I	3534	A/CO TO 169°
91207	2240 08 19.496S 068 09.741I	4019	A/CO TO 158°
91208	57 08 55.235S 068 24.131I	3506	SUNRISE & TURNED OFF REGULATION LIGHTS
91208	145 09 07.605S 068 29.182I	3951	S/B ENG'S
91208	157 09 09.342S 068 29.976I	3966	SURFACE WATER SAMPLING STARTED
91208	207 09 09.612S 068 30.155I	3964	SURFACE WATER SAMPLING FINISHED
91208	227 09 12.632S 068 31.422I	3988	R/UP ENG'S
91208	518 09 55.526S 068 48.789I	4238	A/CO TO 190°
91208	1245 11 55.361S 068 27.142I	3946	S/B ENG'S
91208	1256 11 57.103S 068 26.912I	4035	SURFACE WATER SAMPLING STARTED
91208	1305 11 57.320S 068 26.798I	4068	SURFACE WATER SAMPLING FINISHED
91208	1321 11 59.518S 068 26.467I	4152	R/UP ENG'S
91208	1340 12 04.685S 068 25.515I	3855	SUNSET & PUT ON REGULATION LIGHTS
91209	10 14 59.233S 067 53.992I	3346	A/CO TO 180°
91209	49 15 09.984S 067 53.838I	3208	SUNRISE & TURNED OFF REGULATION LIGHTS
91209	145 15 25.693S 067 53.847I	3408	S/B ENG'S
91209	157 15 27.723S 067 54.037I	3198	SURFACE WATER SAMPLING STARTED
91209	206 15 28.037S 067 54.032I	3000	SURFACE WATER SAMPLING FINISHED
91209	224 15 30.866S 067 54.202I	3360	R/UP ENG'S
91209	749 16 59.955S 067 53.970I	2136	A/CO TO 122°
91209	1245 17 40.027S 069 01.279I	3584	S/B ENG'S
91209	1256 17 40.876S 069 02.703I	3350	SURFACE WATER SAMPLING STARTED

91209	1306 17 41.092S 069 02.853I	3357	SURFACE WATER SAMPLING FINISHED
91209	1320 17 42.046S 069 04.747I	3700	R/UP ENG'S
91209	1350 17 46.049S 069 11.446I	3836	SUNSET & PUT ON REGULATION LIGHTS
91210	27 19 12.776S 071 39.476I	4194	SUNRISE & TURNED OFF REGULATION LIGHTS
91210	559 19 58.460S 072 57.323I	3878	S/B ENG'S
91210	803 19 59.872S 072 33.161I	4313	STOPPED ENG'S
91210	807 19 59.896S 072 33.048I	4289	CHANGED ENG'S TO E/M
91210	815 19 59.977S 072 32.813I	4296 ER-10	NISKIN SAMPLING BY KEVLAR STARTED
91210	852 20 00.297S 072 32.842I	4209 ER-10	NISKIN SAMPLING BY KEVLAR MESSENGER SENT
91210	913 20 00.366S 072 32.926I	4265 ER-10	NISKIN SAMPLING BY KEVLAR MESSENGER ARRIVED
91210	942 20 00.472S 072 33.036I	4222 ER-10	NISKIN SAMPLING BY KEVLAR RESTARTED
91210	1019 20 00.544S 072 33.179I	4208 ER-10	NISKIN SAMPLING BY KEVLAR MESSENGER SENT
91210	1040 20 00.568S 072 33.306I	4164 ER-10	NISKIN SAMPLING BY KEVLAR MESSENGER ARRIVED
91210	1103 20 00.624S 072 33.475I	4171 ER-10	NISKIN SAMPLING BY KEVLAR FINISHED
91210	1202 20 00.033S 072 33.014I	4282 ER-10	LARGE VOLUME SAMPLING STARTED
91210	1210 20 00.047S 072 32.991I	4282 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 100m
91210	1223 20 00.078S 072 32.871I	4294 ER-10	LARGE VOLUME SAMPLING FINISHED
91210	1306 19 59.993S 072 32.924I	4316 ER-10	LARGE VOLUME SAMPLING STARTED
91210	1325 19 59.902S 072 32.928I	4302 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 600m
91210	1345 19 59.798S 072 33.030I	4327 ER-10	SUNSET & PUT ON REGULATION LIGHTS
91210	1346 19 59.798S 072 33.032I	4328 ER-10	LARGE VOLUME SAMPLING FINISHED
91210	1430 19 59.947S 072 32.956I	4292 ER-10	LARGE VOLUME SAMPLING STARTED
91210	1453 19 59.810S 072 33.031I	0 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91210	1521 19 59.559S 072 33.026I	6 ER-10	LARGE VOLUME SAMPLING FINISHED
91210	1600 19 59.987S 072 32.939I	6 ER-10	LARGE VOLUME SAMPLING STARTED
91210	1641 19 59.739S 072 33.056I	4334 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91210	1724 19 59.518S 072 33.211I	0 ER-10	LARGE VOLUME SAMPLING FINISHED
91210	1742 19 59.382S 072 33.243I	0 ER-10	CTD-CMS STARTED
91210	1811 19 59.195S 072 32.993I	0 ER-10	CTD-CMS DEEPEST
91210	1851 19 58.914S 072 32.858I	0 ER-10	CTD-CMS FINISHED
91210	1856 19 58.879S 072 32.833I	0 ER-10	LARGE VOLUME SAMPLING STARTED
91210	2018 19 58.194S 072 32.712I	4139 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 4000m
91210	2139 19 57.501S 072 32.801I	4048 ER-10	LARGE VOLUME SAMPLING FINISHED
91210	2246 19 59.244S 072 33.669I	0 ER-10	GAMOS STARTED
91210	2319 19 58.928S 072 33.429I	4230 ER-10	GAMOS DEEPEST
91210	2346 19 58.788S 072 33.365I	0 ER-10	GAMOS FINISHED
91211	26 20 00.019S 072 32.879I	4317 ER-10	CTD-CMS STARTED
91211	26 20 00.020S 072 32.879I	4320 ER-10	SUNRISE & TURNED OFF REGULATION LIGHTS
91211	204 19 59.628S 072 32.677I	4331 ER-10	CTD-CMS DEEPEST
91211	331 19 59.201S 072 32.554I	4343 ER-10	CTD-CMS FINISHED
91211	513 20 00.029S 072 32.690I	4343 ER-10	CTD-CMS STARTED
91211	615 19 59.879S 072 32.461I	4343 ER-10	CTD-CMS DEEPEST
91211	722 19 59.690S 072 32.313I	4343 ER-10	CTD-CMS FINISHED
91211	731 19 59.682S 072 32.290I	4343 ER-10	IMF STARTED
91211	741 19 59.656S 072 32.282I	4343 ER-10	IMF DEEPEST
91211	750 19 59.633S 072 32.293I	4343 ER-10	IMF FINISHED
91211	845 20 00.088S 072 32.884I	4343 ER-10	CTD-CMS STARTED
91211	929 20 00.083S 072 32.508I	4343 ER-10	CTD-CMS DEEPEST
91211	1014 20 00.121S 072 32.441I	4343 ER-10	CTD-CMS FINISHED
91211	1141 20 00.041S 072 32.927I	4343 ER-10	CTD-CMS STARTED
91211	1205 20 00.057S 072 32.770I	4343 ER-10	CTD-CMS DEEPEST
91211	1233 20 00.110S 072 32.794I	4343 ER-10	CTD-CMS FINISHED
91211	1342 19 59.999S 072 33.020I	4343 ER-10	SUNSET & PUT ON REGULATION LIGHTS
91211	1348 20 00.004S 072 33.009I	4343 ER-10	CTD-CMS STARTED
91211	1401 20 00.024S 072 32.919I	4343 ER-10	CTD-CMS DEEPEST
91211	1419 20 00.062S 072 32.815I	4343 ER-10	CTD-CMS FINISHED
91211	1526 20 00.039S 072 33.073I	4343 ER-10	CTD-CMS STARTED
91211	1540 20 00.064S 072 32.944I	4343 ER-10	CTD-CMS DEEPEST
91211	1604 20 00.076S 072 32.775I	4343 ER-10	CTD-CMS FINISHED
91211	1705 20 00.114S 072 32.903I	4343 ER-10	CTD-CMS STARTED
91211	1719 20 00.147S 072 32.842I	4343 ER-10	CTD-CMS DEEPEST
91211	1736 20 00.142S 072 32.712I	4343 ER-10	CTD-CMS FINISHED
91211	2001 19 59.984S 072 33.028I	4343 ER-10	CTD-CMS STARTED
91211	2015 19 59.977S 072 33.049I	4343 ER-10	CTD-CMS DEEPEST
91211	2036 19 59.986S 072 32.999I	4343 ER-10	CTD-CMS FINISHED
91212	23 20 00.123S 072 32.862I	4318 ER-10	SUNRISE & TURNED OFF REGULATION LIGHTS

91212	700 20 00.067S 072 32.975I	4306 ER-10	CTD-CMS STARTED
91212	836 20 00.048S 072 32.575I	5 ER-10	CTD-CMS DEEPEST
91212	1005 19 59.916S 072 32.347I	4243 ER-10	CTD-CMS FINISHED
91212	1031 19 59.946S 072 31.881I	4200 ER-10	LARGE VOLUME SAMPLING STARTED
91212	1149 19 59.854S 072 31.859I	4230 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 4000m
91212	1211 19 59.810S 072 31.853I	4208 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 3000m
91212	1300 19 59.763S 072 31.884I	4230 ER-10	LARGE VOLUME SAMPLING FINISHED
91212	1343 20 00.005S 072 32.998I	4290 ER-10	SUNSET & PUT ON REGULATION LIGHTS
91212	1353 20 00.026S 072 33.025I	4307 ER-10	LARGE VOLUME SAMPLING STARTED
91212	1357 20 00.030S 072 33.020I	4281 ER-10	LARGE VOLUME SAMPLING FINISHED
91212	1357 20 00.031S 072 33.016I	4281 ER-10	LARGE VOLUME SAMPLING STARTED AGAIN
91212	1434 20 00.061S 072 33.118I	4282 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91212	1451 20 00.093S 072 33.150I	4280 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91212	1459 20 00.097S 072 33.160I	4282 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 600m
91212	1507 20 00.099S 072 33.168I	4302 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 200m
91212	1517 20 00.099S 072 33.184I	4291 ER-10	LARGE VOLUME SAMPLING FINISHED
91212	1535 20 00.096S 072 33.120I	4283 ER-10	CTD-CMS STARTED
91212	1540 20 00.103S 072 33.104I	4298 ER-10	CTD-CMS FINISHED
91212	1540 20 00.103S 072 33.104I	4285 ER-10	CTD-CMS STARTED AGAIN
91212	1631 19 59.914S 072 32.898I	4308 ER-10	CTD-CMS DEEPEST
91212	1728 19 59.710S 072 32.798I	4320 ER-10	CTD-CMS FINISHED
91212	1734 19 59.720S 072 32.741I	4316 ER-10	LARGE VOLUME SAMPLING STARTED
91212	1751 19 59.805S 072 32.804I	4320 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 400m
91212	1756 19 59.805S 072 32.816I	4320 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 300m
91212	1801 19 59.815S 072 32.846I	4327 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 200m
91212	1806 19 59.827S 072 32.866I	4319 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 150m
91212	1813 19 59.843S 072 32.851I	4318 ER-10	LARGE VOLUME SAMPLING FINISHED
91212	1846 19 59.980S 072 32.961I	4292 ER-10	LARGE VOLUME SAMPLING STARTED
91212	1853 20 00.044S 072 32.970I	4321 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 100m
91212	1855 20 00.067S 072 32.977I	4302 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 75m
91212	1858 20 00.099S 072 32.983I	4302 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 50m
91212	1905 20 00.159S 072 33.006I	4286 ER-10	LARGE VOLUME SAMPLING FINISHED
91212	1935 20 00.234S 072 33.006I	4300 ER-10	LARGE VOLUME SAMPLING STARTED
91212	1938 20 00.257S 072 33.000I	4301 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 25m
91212	1942 20 00.288S 072 32.983I	4298 ER-10	LARGE VOLUME SAMPLING COVER CLOSED 10m
91212	1947 20 00.327S 072 32.956I	4285 ER-10	LARGE VOLUME SAMPLING FINISHED
91212	2019 20 00.393S 072 32.920I	4254 ER-10	CTD-CMS STARTED
91212	2103 20 00.542S 072 32.947I	4236 ER-10	CTD-CMS DEEPEST
91212	2137 20 00.599S 072 33.012I	4182 ER-10	CTD-CMS FINISHED
91212	2210 20 00.358S 072 32.896I	4272 ER-10	MULTIPLE CORER STARTED
91212	2339 19 59.778S 072 32.838I	5408 ER-10	MULTIPLE CORER HIT BOTTOM
91212	2341 19 59.780S 072 32.835I	5347 ER-10	MULTIPLE CORER LEFT BOTTOM
91213	23 19 59.992S 072 33.078I	0 ER-10	SUNRISE & TURNED OFF REGULATION LIGHTS
91213	46 20 00.067S 072 33.119I	4279 ER-10	MULTIPLE CORER FINISHED
91213	101 20 00.073S 072 33.005I	4321 ER-10	CTD-CMS STARTED
91213	127 20 00.010S 072 32.972I	4290 ER-10	CTD-CMS DEEPEST
91213	151 20 00.011S 072 32.953I	4314 ER-10	CTD-CMS FINISHED
91213	407 20 00.020S 072 32.965I	4311 ER-10	CTD-CMS STARTED
91213	420 20 00.048S 072 32.909I	4319 ER-10	CTD-CMS DEEPEST
91213	439 20 00.094S 072 32.846I	4292 ER-10	CTD-CMS FINISHED
91213	658 20 00.051S 072 32.990I	4290 ER-10	CTD-CMS STARTED
91213	710 20 00.082S 072 32.862I	4306 ER-10	CTD-CMS DEEPEST
91213	726 20 00.125S 072 32.720I	4250 ER-10	CTD-CMS FINISHED
91213	739 20 00.226S 072 32.623I	4202 ER-10	No.2 WINCH FREE FALL STARTED
91213	854 20 00.384S 072 32.228I	4127 ER-10	FREE FALL DEEPEST
91213	1106 20 00.357S 072 32.081I	4138 ER-10	FREE FALL FINISHED
91213	1343 20 00.005S 072 33.008I	4293 ER-10	SUNSET & PUT ON REGULATION LIGHTS
91213	1426 20 00.039S 072 32.945I	4296 ER-10	GAMOS STARTED
91213	1451 20 00.049S 072 32.829I	4300 ER-10	GAMOS DEEPEST
91213	1527 19 59.995S 072 32.618I	4245 ER-10	GAMOS FINISHED
91213	1541 20 00.079S 072 32.350I	4160	CHANGED ENG'S TO T/M
91213	1605 20 00.079S 072 27.759I	3951	R/UP ENG'S & S/CO. ON 270°
91213	2000 19 59.995S 071 17.965I	4529	PUT SHIP'S CLOCKS ABACK 1HR
91214	34 20 00.000S 069 55.981I	3572	SUNRISE & TURNED OFF REGULATION LIGHTS
91214	1024 20 00.204S 067 00.451I	0	ENTERED EEZ OF REPUBLIC OF MAURITIUS
91214	1411 20 00.142S 065 52.919I	0	SUNSET & PUT ON REGULATION LIGHTS

91215	103 20 00.206S 062 47.005I	0	SUNRISE & TURNED OFF REGULATION LIGHTS
91215	500 20 00.160S 061 39.871I	0	S/B ENG'S
91215	1407 20 00.237S 059 46.555I	0	CHANGED ENG'S TO S/M
91215	1436 20 00.248S 059 41.542I	0	SUNSET & PUT ON REGULATION LIGHTS
91216	12 19 59.716S 057 59.094I	0	A/CO TO 285°
91216	124 19 56.736S 057 47.295I	0	SUNRISE & TURNED OFF REGULATION LIGHTS
91216	237 19 54.731S 057 35.534I	0	A/CO TO 261°
91216	342 19 56.789S 057 24.725I	0	A/CO TO 174°
91216	431 20 04.147S 057 24.916I	0	USED HELM VAR'LY
91216	455 20 05.297S 057 24.914I	0	CHANGED ENG'S TO E/M
91216	734 20 05.356S 057 25.932I	0	CHANGED ENG'S TO S/M
91216	816 20 07.766S 057 27.417I	0	STOPPED ENG'S

## 5.3. Leg-3

Date	Time (GMT	Latitude	Longitude	Depth(m)	Station	Ship logs
91219	805	20 09.460S	057 29.886E	0		
91219	1056	20 07.909S	057 25.698E	0		R/UP ENG'S
91219	1108	20 08.212S	057 22.061E	0		A/CO TO 200°
91219	1231	20 29.990S	057 13.844E	0		A/CO TO 143°
91219	1448	20 59.811S	057 37.127E	0		SUNRISE & TURNED OFF REGULATION LIGHTS
91220	113	23 17.750S	059 26.891E	0		SUNRISE & TURNED OFF REGULATION LIGHTS
91220	128	23 21.057S	059 29.560E	0		CLEARED OUT EEZ OF REP. OF MAURITIUS
91220	137	23 22.900S	059 31.048E	0		TURNED ON PDR
91220	142	23 23.890S	059 31.862E	0		TURNED ON GRAVITY
91220	236	23 35.328S	059 41.049E	4394		TURNED ON SEABEAM
91220	900	24 57.278S	060 47.548E	4124		COM'CED LIFEBOAT STATION DRILL
91220	930	25 03.791S	060 52.938E	5042		FINISHED LIFEBOAT STATION DRILL
91220	1443	26 15.339S	061 51.448E	4696		SUNSET & PUT ON REGULATION LIGHTS
91221	43	28 26.594S	063 41.094E	3266		SUNRISE & TURNED OFF REGULATION LIGHTS
91221	649	29 47.526S	064 49.538E	4495		S/B ENG'S
91221	700	29 49.273S	064 51.118E	4590		8 SHAPE ROTATION RIGHT TURNING STARTED
91221	710	29 49.226S	064 51.209E	4564		8 SHAPE ROTATION LEFT TURNING STARTED
91221	720	29 49.275S	064 51.247E	4561		8 SHAPE ROTATION TURNING FINISHED
91221	815	29 59.927S	064 59.766E	4652		STOPPED ENG'S
91221	822	30 00.016S	064 59.841E	4671		CHANGED ENG'S TO E/M
91221	826	30 00.042S	064 59.848E	4673 ER-11		CTD-CMS STARTED
91221	1006	30 00.022S	064 59.953E	4653 ER-11		CTD-CMS DEEPEST
91221	1132	30 00.018S	064 59.976E	4658 ER-11		CTD-CMS FINISHED
91221	1154	30 00.013S	065 00.056E	4648 ER-11		LARGE VOLUME SAMPLING STARTED
91221	1235	29 59.989S	065 00.372E	4612 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 2000m
91221	1251	29 59.982S	065 00.419E	4625 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 1500m
91221	1259	29 59.981S	065 00.459E	4635 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 1250m
91221	1305	29 59.976S	065 00.516E	4632 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 1000m
91221	1329	29 59.990S	065 00.658E	4652 ER-11		LARGE VOLUME SAMPLING FINISHED
91221	1357	29 59.977S	064 59.902E	4652 ER-11		CTD-CMS STARTED
91221	1440	29 59.925S	065 00.001E	4647 ER-11		SUNSET & PUT ON REGULATION LIGHTS
91221	1513	29 59.917S	065 00.099E	4626 ER-11		CTD-CMS DEEPEST
91221	1641	30 00.143S	064 59.971E	4666 ER-11		CTD-CMS FINISHED
91221	1659	29 59.957S	065 00.055E	4640 ER-11		LARGE VOLUME SAMPLING STARTED
91221	1719	29 59.989S	065 00.085E	4633 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 800m
91221	1725	30 00.012S	065 00.056E	4646 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 600m
91221	1730	30 00.030S	065 00.023E	4652 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 400m
91221	1735	30 00.040S	065 00.012E	4652 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 300m
91221	1744	30 00.038S	065 00.059E	4661 ER-11		LARGE VOLUME SAMPLING FINISHED
91221	1818	29 59.983S	064 59.926E	4650 ER-11		CTD-CMS STARTED
91221	1918	29 59.969S	065 00.058E	4641 ER-11		CTD-CMS DEEPEST
91221	2022	30 00.078S	065 00.094E	4650 ER-11		CTD-CMS FINISHED
91221	2028	30 00.112S	065 00.085E	4666 ER-11		LARGE VOLUME SAMPLING STARTED
91221	2038	30 00.063S	065 00.174E	4641 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 200m
91221	2042	30 00.043S	065 00.216E	4641 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 150m
91221	2045	30 00.032S	065 00.248E	4644 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 100m
91221	2048	30 00.022S	065 00.277E	4612 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 80m
91221	2055	29 59.987S	065 00.345E	4623 ER-11		LARGE VOLUME SAMPLING FINISHED
91221	2130	29 59.986S	065 00.010E	4652 ER-11		LARGE VOLUME SAMPLING STARTED
91221	2135	29 59.968S	065 00.052E	4644 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 60m
91221	2137	29 59.944S	065 00.088E	4641 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 40m
91221	2141	29 59.922S	065 00.125E	4626 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 20m
91221	2143	29 59.908S	065 00.158E	4626 ER-11		LARGE VOLUME SAMPLING COVER CLOSED 10m
91221	2147	29 59.899S	065 00.200E	4632 ER-11		LARGE VOLUME SAMPLING FINISHED
91221	2216	30 00.029S	065 00.054E	4643 ER-11		CTD-CMS STARTED
91221	2253	30 00.042S	065 00.207E	4644 ER-11		CTD-CMS DEEPEST
91221	2331	29 59.957S	065 00.255E	4635 ER-11		CTD-CMS FINISHED
91221	2349	29 59.928S	064 59.998E	4639 ER-11		MULTIPLE CORER STARTED
91222	35	29 59.923S	064 59.995E	4679 ER-11		SUNRISE & TURNED OFF REGULATION LIGHTS
91222	118	30 00.009S	064 59.909E	5 ER-11		MULTIPLE CORER HIT BOTTOM
91222	120	30 00.011S	064 59.908E	4712 ER-11		MULTIPLE CORER LEFT BOTTOM
91222	236	30 00.043S	064 59.833E	4672 ER-11		MULTIPLE CORER FINISHED
91222	248	29 59.993S	064 59.933E	4662 ER-11		CTD-CMS STARTED

91222	307 29 59.881S 065 00.016I	4628 ER-11	CTD-CMS DEEPEST
91222	332 29 59.926S 065 00.063I	4637 ER-11	CTD-CMS FINISHED
91222	345 29 59.852S 065 00.151I	4634 ER-11	NORPAC NET STARTED
91222	403 29 59.790S 065 00.283I	4644 ER-11	NORPAC NET FINISHED
91222	459 29 59.978S 064 59.996I	4644 ER-11	CTD-CMS STARTED
91222	510 29 59.961S 065 00.038I	4637 ER-11	CTD-CMS DEEPEST
91222	523 29 59.970S 065 00.092I	4628 ER-11	CTD-CMS FINISHED
91222	641 29 59.908S 064 59.958I	4633 ER-11	CTD-CMS STARTED
91222	652 29 59.850S 064 59.974I	4622 ER-11	CTD-CMS DEEPEST
91222	707 29 59.804S 064 59.920I	4622 ER-11	CTD-CMS FINISHED
91222	718 29 59.778S 064 59.879I	4620 ER-11	CHANGED ENG'S TO T/M
91222	733 30 00.129S 064 59.665I	4704 ER-11	SLOW AHEAD ENG'S
91222	739 30 00.126S 064 59.545I	4740 ER-11	LET GO ARGO FLOAT
91222	800 30 02.739S 064 57.447I	4712 ER-11	R/UP ENG'S & S/CO ON <218>
91222	1450 31 29.576S 063 37.888I	4971	SUNSET & PUT ON REGULATION LIGHTS
91223	39 33 31.554S 061 43.427I	4776	SUNRISE & TURNED OFF REGULATION LIGHTS
91223	1523 36 35.426S 058 46.196I	5026	SUNSET & PUT ON REGULATION LIGHTS
91223	2050 37 43.742S 057 38.464I	5232	S/B ENG'S
91223	2102 37 44.898S 057 37.101I	5331	STOPPED ENG'S
91223	2110 37 44.946S 057 37.190I	5333	CHANGED ENG'S TO E/M
91223	2116 37 44.982S 057 37.249I	5319 ER-12	CTD-CMS STARTED
91223	2310 37 45.143S 057 37.136I	5314 ER-12	CTD-CMS DEEPEST
91224	45 37 45.322S 057 37.100I	5327 ER-12	SUNRISE & TURNED OFF REGULATION LIGHTS
91224	100 37 45.375S 057 37.037I	5332 ER-12	CTD-CMS FINISHED
91224	142 37 45.124S 057 36.876I	5265 ER-12	LARGE VOLUME SAMPLING STARTED
91224	220 37 45.465S 057 36.441I	5293 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 200m
91224	231 37 45.561S 057 36.269I	5280 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91224	237 37 45.622S 057 36.220I	5276 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 1250m
91224	243 37 45.682S 057 36.181I	5274 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91224	306 37 45.894S 057 35.949I	5254 ER-12	LARGE VOLUME SAMPLING FINISHED
91224	337 37 44.889S 057 36.999I	5290 ER-12	CTD-CMS STARTED
91224	502 37 45.108S 057 36.570I	5227 ER-12	CTD-CMS DEEPEST
91224	633 37 45.284S 057 36.302I	5227 ER-12	CTD-CMS FINISHED
91224	703 37 45.059S 057 36.847I	5274 ER-12	LARGE VOLUME SAMPLING STARTED
91224	725 37 45.159S 057 36.426I	5226 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91224	734 37 45.209S 057 36.296I	5224 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 600m
91224	739 37 45.239S 057 36.226I	5227 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 400m
91224	742 37 45.260S 057 36.175I	5234 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 300m
91224	752 37 45.311S 057 36.061I	5237 ER-12	LARGE VOLUME SAMPLING FINISHED
91224	829 37 44.860S 057 37.099I	5331 ER-12	CTD-CMS STARTED
91224	941 37 45.004S 057 36.951I	5287 ER-12	CTD-CMS DEEPEST
91224	1048 37 45.316S 057 36.682I	5263 ER-12	CTD-CMS FINISHED
91224	1057 37 45.363S 057 36.619I	5257 ER-12	LARGE VOLUME SAMPLING STARTED
91224	1107 37 45.502S 057 36.335I	5286 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 200m
91224	1111 37 45.551S 057 36.245I	5278 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 150m
91224	1115 37 45.597S 057 36.140I	5271 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 100m
91224	1118 37 45.638S 057 36.073I	5266 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 80m
91224	1124 37 45.734S 057 35.942I	5264 ER-12	LARGE VOLUME SAMPLING FINISHED
91224	1206 37 44.896S 057 36.872I	5278 ER-12	LARGE VOLUME SAMPLING STARTED
91224	1212 37 44.873S 057 36.794I	5270 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 60m
91224	1216 37 44.868S 057 36.715I	5254 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 40m
91224	1221 37 44.867S 057 36.592I	5246 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 20m
91224	1222 37 44.866S 057 36.555I	0 ER-12	LARGE VOLUME SAMPLING COVER CLOSED 10m
91224	1226 37 44.868S 057 36.455I	5223 ER-12	LARGE VOLUME SAMPLING FINISHED
91224	1242 37 44.856S 057 36.135I	5220 ER-12	CTD-CMS STARTED
91224	1340 37 45.333S 057 35.419I	5242 ER-12	CTD-CMS DEEPEST
91224	1438 37 45.845S 057 35.094I	5237 ER-12	CTD-CMS FINISHED
91224	1532 37 44.840S 057 37.837I	5385 ER-12	SUNSET & PUT ON REGULATION LIGHTS
91224	1541 37 44.867S 057 37.890I	5390 ER-12	MULTIPLE CORER STARTED
91224	1726 37 45.091S 057 37.112I	5331 ER-12	MULTIPLE CORER HIT BOTTOM
91224	1728 37 45.094S 057 37.105I	5326 ER-12	MULTIPLE CORER LEFT BOTTOM
91224	1854 37 45.056S 057 36.630I	5245 ER-12	MULTIPLE CORER FINISHED
91224	1925 37 45.123S 057 37.119I	5314 ER-12	CTD-CMS STARTED
91224	2001 37 45.271S 057 36.956I	5300 ER-12	CTD-CMS DEEPEST
91224	2040 37 45.464S 057 36.847I	5314 ER-12	CTD-CMS FINISHED
91224	2052 37 45.609S 057 36.967I	5320 ER-12	NORPAC NET STARTED



91224	2102 37 45.713S 057 37.062I	5320 ER-12	NORPAC NET DEEPEST
91224	2108 37 45.786S 057 37.114I	5332 ER-12	NORPAC NET FINISHED
91224	2110 37 45.813S 057 37.131I	5330 ER-12	NORPAC(BREEDING) NET STRATED
91224	2116 37 45.842S 057 37.111I	5329 ER-12	NORPAC(BREEDING) NET DEEPEST
91224	2122 37 45.855S 057 37.065I	5326 ER-12	NORPAC(BREEDING) NET FINISHED
91224	2203 37 44.989S 057 36.837I	5270 ER-12	CTD-CMS STARTED
91224	2228 37 45.163S 057 36.845I	5270 ER-12	CTD-CMS DEEPEST
91224	2255 37 45.332S 057 36.716I	5274 ER-12	CTD-CMS FINISHED
91225	24 37 45.002S 057 36.927I	5280 ER-12	CTD-CMS STARTED
91225	38 37 45.013S 057 36.790I	5264 ER-12	CTD-CMS DEEPEST
91225	45 37 45.034S 057 36.735I	5262 ER-12	SUNRISE & TURNED OFF REGULATION LIGHTS
91225	55 37 45.059S 057 36.604I	5232 ER-12	CTD-CMS FINISHED
91225	142 37 46.282S 057 38.498I	5352 ER-12	MULTIPLE CORER STARTED
91225	338 37 45.875S 057 37.864I	5387 ER-12	MULTIPLE CORER HIT BOTTOM
91225	341 37 45.878S 057 37.866I	5387 ER-12	MULTIPLE CORER LEFT BOTTOM
91225	507 37 45.427S 057 37.323I	5411 ER-12	MULTIPLE CORER FINISHED
91225	536 37 45.005S 057 36.990I	5308 ER-12	CTD-CMS STARTED
91225	548 37 45.036S 057 36.915I	5273 ER-12	CTD-CMS DEEPEST
91225	603 37 45.171S 057 36.808I	5274 ER-12	CTD-CMS FINISHED
91225	617 37 45.291S 057 36.797I	5267 ER-12	CHANGED ENG'S TO T/M
91225	620 37 45.368S 057 36.791I	5272 ER-12	LET GO ARGO FLOAT
91225	646 37 49.655S 057 35.392I	5323	R/UP ENG'S & S/CO ON 193°
91225	1544 40 10.132S 056 52.911I	4845	SUNSET & PUT ON REGULATION LIGHTS
91225	2355 42 24.766S 056 10.178I	4454	SUNRISE & TURNED OFF REGULATION LIGHTS
91226	649 44 03.802S 055 37.600I	4306	ENTERED EEZ OF FRENCH
91226	1614 46 21.466S 054 51.115I	4306	SUNSET & PUT ON REGULATION LIGHTS
91226	1700 46 32.991S 054 46.467I	4306	PUT SHIP'S CLOCKS ABACK 1 HOUR (GMT+3H)
91227	21 48 24.208S 054 08.042I	4306	SUNRISE & TURNED OFF REGULATION LIGHTS
91227	521 49 40.109S 053 40.044I	0	CLEARED OUT EEZ OF FRENCH
91227	521 49 40.296S 053 39.981I	0	S/B ENG'S
91227	545 49 43.523S 053 38.997I	4431	PROTON SURVEY STARTED
91227	618 49 48.425S 053 37.769I	4412	R/UP ENG'S
91227	635 49 52.952S 053 36.107I	4409	S/B ENG'S
91227	644 49 54.665S 053 35.336I	4410	LET GO XCTD
91227	658 49 57.341S 053 34.179I	4417	R/UP ENG'S
91227	1011 50 45.728S 053 15.771I	4499	A/CO TO 207°
91227	1657 52 20.732S 051 58.531I	4621	SUNSET & PUT ON REGULATION LIGHTS
91227	2149 53 30.018S 051 00.047I	3198 ER-13	COM'CED BOTTOM SURVEY
91228	4 54 04.430S 051 08.360I	1668 ER-13	SUNRISE & TURNED OFF REGULATION LIGHTS
91228	100 54 18.691S 051 12.369I	1216 ER-13	S/B ENG'S
91228	502 54 50.254S 051 30.173I	2313 ER-13	FINISHED BOTTOM SURVEY
91228	505 54 50.991S 051 30.074I	0	S/CO ON 222°
91228	515 54 52.741S 051 26.932I	3432	R/UP ENG'S
91228	556 55 00.379S 051 14.060I	5221	P'd LAT 55-00.0S
91228	1752 57 22.118S 047 29.076I	5383	SUNSET & PUT ON REGULATION LIGHTS
91228	2350 58 34.040S 045 29.242I	5352	SUNRISE & TURNED OFF REGULATION LIGHTS
91229	335 59 18.946S 044 13.688I	5336	A/CO TO 217°
91229	1550 61 55.017S 040 14.890I	5204	S/B ENG'S USED ENG'S VAR'LY
91229	1550 61 55.024S 040 14.877I	5206	USED HELM VAR'LY
91229	1557 61 55.948S 040 13.294I	5202	PROTON SURVEY FINISHED
91229	1641 61 59.976S 040 04.736I	5202	CHANGED ENG'S TO E/M
91229	1708 61 59.889S 040 04.491I	5201 ER-14	MULTIPLE CORER STARTED
91229	1858 61 59.994S 040 05.127I	6 ER-14	MULTIPLE CORER HIT BOTTOM
91229	1902 61 59.972S 040 05.094I	5150 ER-14	MULTIPLE CORER LEFT BOTTOM
91229	1919 61 59.947S 040 05.131I	5145 ER-14	SUNSET & PUT ON REGULATION LIGHTS
91229	2023 61 59.952S 040 06.004I	5201 ER-14	MULTIPLE CORER FINISHED
91229	2048 62 00.065S 040 06.165I	5203 ER-14	CTD-CMS STARTED
91229	2233 61 59.959S 040 05.978I	5202 ER-14	CTD-CMS DEEPEST
91229	2332 61 59.835S 040 05.634I	5201 ER-14	SUNRISE & TURNED OFF REGULATION LIGHTS
91230	17 61 59.686S 040 05.522I	5204 ER-14	CTD-CMS FINISHED
91230	56 62 00.005S 040 05.153I	5202 ER-14	LARGE VOLUME SAMPLING STARTED
91230	106 62 00.031S 040 05.110I	5203 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 100m
91230	123 62 00.063S 040 05.062I	5206 ER-14	LARGE VOLUME SAMPLING FINISHED
91230	216 61 59.971S 040 04.920I	5204 ER-14	LARGE VOLUME SAMPLING STARTED
91230	241 61 59.879S 040 04.799I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 600m
91230	303 61 59.860S 040 04.653I	5202 ER-14	LARGE VOLUME SAMPLING FINISHED

91230	350 61 59.950S 040 04.724I	5201 ER-14	LARGE VOLUME SAMPLING STARTED
91230	423 61 59.881S 040 04.792I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91230	451 61 59.747S 040 05.068I	5204 ER-14	LARGE VOLUME SAMPLING FINISHED
91230	610 61 59.910S 040 05.099I	5203 ER-14	CTD-CMS STARTED
91230	646 61 59.871S 040 05.103I	5202 ER-14	RECOVERED CTD-CMS
91230	1004 61 59.921S 040 05.156I	5202 ER-14	COM'CED SAMPLING SURFACE WATER
91230	1025 62 00.063S 040 04.959I	5202 ER-14	FINISHED SAMPLING SURFACE WATER
91230	1044 61 59.991S 040 05.065I	5202 ER-14	NORPAC NET STARTED
91230	1057 61 59.893S 040 05.049I	5201 ER-14	NORPAC NET DEEPEST
91230	1103 61 59.863S 040 05.028I	5201 ER-14	NORPAC NET FINISHED
91230	1105 61 59.859S 040 05.016I	5202 ER-14	NORPAC NET STARTED (BREEDING NET)
91230	1115 61 59.805S 040 04.961I	5202 ER-14	ABOVE NET DEEPEST
91230	1123 61 59.751S 040 04.944I	5202 ER-14	NORPAC NET FINISHED (BREEDING NET)
91230	1141 61 59.739S 040 05.014I	5203 ER-14	CTD-CMS STARTED
91230	1309 61 59.332S 040 04.603I	5205 ER-14	CTD-CMS DEEPEST
91230	1442 61 58.760S 040 04.227I	5206 ER-14	CTD-CMS FINISHED
91230	1520 62 00.035S 040 05.019I	5205 ER-14	LARGE VOLUME SAMPLING STARTED
91230	1623 61 59.861S 040 04.896I	5203 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 2500m
91230	1724 61 59.543S 040 05.139I	5206 ER-14	LARGE VOLUME SAMPLING FINISHED
91230	1818 61 59.940S 040 05.053I	5203 ER-14	LARGE VOLUME SAMPLING STARTED
91230	1912 62 00.034S 040 05.621I	5203 ER-14	SUNSET & PUT ON REGULATION LIGHTS
91230	1940 61 59.951S 040 05.939I	5201 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 5000m
91230	2114 61 59.699S 040 07.627I	5202 ER-14	LARGE VOLUME SAMPLING FINISHED
91230	2152 61 59.913S 040 05.024I	5203 ER-14	CTD-CMS STARTED
91230	2308 61 59.602S 040 04.778I	5202 ER-14	CTD-CMS DEEPEST
91230	2333 61 59.482S 040 04.684I	5205 ER-14	SUNRISE & TURNED OFF REGULATION LIGHTS
91231	12 61 59.287S 040 04.540I	5206 ER-14	CTD-CMS FINISHED
91231	39 62 00.071S 040 05.158I	5203 ER-14	MULTIPLE CORER STARTED
91231	215 62 00.000S 040 05.007I	5149 ER-14	MULTIPLE CORER HIT BOTTOM
91231	218 61 59.988S 040 05.006I	5149 ER-14	MULTIPLE CORER LEFT BOTTOM
91231	345 61 59.884S 040 04.293I	5202 ER-14	MULTIPLE CORER FINISHED
91231	416 62 00.387S 040 05.120I	5198 ER-14	CTD-CMS STARTED
91231	515 62 00.495S 040 04.650I	5198 ER-14	CTD-CMS DEEPEST
91231	610 62 00.512S 040 04.639I	5198 ER-14	CTD-CMS FINISHED
91231	804 61 59.790S 040 04.235I	5202 ER-14	CTD-CMS STARTED
91231	845 61 59.766S 040 04.150I	5202 ER-14	CTD-CMS DEEPEST
91231	919 61 59.806S 040 03.941I	5202 ER-14	CTD-CMS FINISHED
91231	943 62 00.002S 040 05.263I	5201 ER-14	LARGE VOLUME SAMPLING STARTED
91231	1022 61 59.889S 040 05.877I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 2000m
91231	1032 61 59.887S 040 06.052I	5203 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 1500m
91231	1039 61 59.892S 040 06.146I	5201 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 1250m
91231	1045 61 59.884S 040 06.250I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 1000m
91231	1107 61 59.845S 040 06.644I	5201 ER-14	LARGE VOLUME SAMPLING FINISHED
91231	1132 61 59.985S 040 04.939I	5204 ER-14	CTD-CMS STARTED
91231	1202 62 00.030S 040 04.951I	5200 ER-14	CTD-CMS DEEPEST
91231	1226 62 00.026S 040 04.791I	5201 ER-14	CTD-CMS FINISHED
91231	1233 62 00.029S 040 04.777I	5200 ER-14	LARGE VOLUME SAMPLING STARTED
91231	1251 61 59.986S 040 04.968I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 800m
91231	1256 61 59.981S 040 05.000I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 600m
91231	1301 61 59.968S 040 05.033I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 400m
91231	1305 61 59.961S 040 05.053I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 300m
91231	1318 61 59.921S 040 05.149I	5202 ER-14	LARGE VOLUME SAMPLING FINISHED
91231	1347 62 00.072S 040 04.959I	5204 ER-14	CTD-CMS STARTED
91231	1400 62 00.051S 040 04.940I	5204 ER-14	CTD-CMS DEEPEST
91231	1415 62 00.002S 040 04.929I	5204 ER-14	CTD-CMS FINISHED
91231	1430 61 59.935S 040 04.966I	5202 ER-14	LARGE VOLUME SAMPLING STARTED
91231	1442 61 59.885S 040 04.944I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 200m
91231	1445 61 59.875S 040 04.934I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 150m
91231	1449 61 59.859S 040 04.914I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 100m
91231	1452 61 59.852S 040 04.915I	5203 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 80m
91231	1459 61 59.838S 040 04.908I	5202 ER-14	LARGE VOLUME SAMPLING FINISHED
91231	1542 62 00.033S 040 05.020I	5202 ER-14	LARGE VOLUME SAMPLING STARTED
91231	1547 62 00.019S 040 05.012I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 60m
91231	1549 62 00.006S 040 04.999I	5204 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 40m
91231	1552 61 59.990S 040 04.986I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 20m
91231	1554 61 59.976S 040 04.975I	5202 ER-14	LARGE VOLUME SAMPLING COVER CLOSED 10m

91231	1558 61 59.958S 040 04.953I	5202 ER-14	LARGE VOLUME SAMPLING FINISHED
91231	1618 61 59.959S 040 04.864I	5201 ER-14	CTD-CMS STARTED
91231	1629 61 59.916S 040 04.773I	5202 ER-14	CTD-CMS DEEPEST
91231	1644 61 59.896S 040 04.589I	5202 ER-14	CTD-CMS FINISHED
91231	1700 62 00.032S 040 04.322I	5202 ER-14	CHANGED ENG'S TO T/M
91231	1730 62 03.558S 039 56.388I	5179	R/UP ENG'S
91231	1922 62 23.600S 039 09.157I	5084	SUNSET & PUT ON REGULATION LIGHTS
91231	2327 63 08.043S 037 22.131I	5056	SUNRISE & TURNED OFF REGULATION LIGHTS
100101	810 64 43.683S 033 20.604I	3499	USED HELM VAR'LY & COM'CED BOTTOM SURVEY
100101	941 65 08.478S 033 18.944I	3249	S/B ENG'S
100101	1036 65 00.810S 033 19.016I	3302	STOPPED ENG'S
100101	1040 65 00.875S 033 18.871I	3303	CHANGED ENG'S TO E/M
100101	1054 65 01.017S 033 18.844I	3303 ER-15	PISTON CORER STARTED
100101	1220 65 00.743S 033 19.679I	3253 ER-15	PISTON CORER HIT BOTTOM
100101	1222 65 00.748S 033 19.657I	3253 ER-15	PISTON CORER LEFT BOTTOM
100101	1330 65 00.754S 033 19.979I	3253 ER-15	PISTON CORER FINISHED
100101	1344 65 00.767S 033 20.027I	3253 ER-15	NORPAC NET STARTED
100101	1413 65 00.642S 033 20.336I	3253 ER-15	NORPAC NET FINISHED
100101	1415 65 00.632S 033 20.369I	3253 ER-15	NORPAC NET STARTED
100101	1440 65 00.567S 033 20.327I	3253 ER-15	NORPAC NET FINISHED
100101	1440 65 00.566S 033 20.327I	3253 ER-15	NORPAC NET STARTED
100101	1500 65 00.501S 033 20.424I	3253 ER-15	NORPAC NET FINISHED
100101	1501 65 00.498S 033 20.435I	3253 ER-15	NORPAC NET STARTED
100101	1523 65 00.410S 033 20.692I	3253 ER-15	NORPAC NET FINISHED
100101	1541 65 00.452S 033 20.152I	3253 ER-15	MULTIPLE CORER STARTED
100101	1645 65 00.591S 033 19.869I	3252 ER-15	MULTIPLE CORER HIT BOTTOM
100101	1648 65 00.592S 033 19.847I	3252 ER-15	MULTIPLE CORER LEFT BOTTOM
100101	1739 65 00.430S 033 20.372I	3300 ER-15	MULTIPLE CORER FINISHED
100101	1749 65 00.462S 033 20.109I	3301 ER-15	CHANGED ENG'S TO T/M
100101	2000 65 06.157S 033 20.180I	3153 ER-15	R/UP ENG'S
100101	2051 64 52.742S 033 16.400I	3299 ER-15	SUNSET & PUT ON REGULATION LIGHTS
100101	2318 64 14.925S 033 06.207I	4835	SUNRISE & TURNED OFF REGULATION LIGHTS
100102	556 62 35.514S 032 35.281I	5151	S/B ENG'S
100102	606 62 35.900S 032 34.625I	5150	CHANGED ENG'S TO S/M
100102	909 62 33.468S 032 33.035I	5153	R/UP ENG'S
100102	1105 62 02.616S 032 30.834I	5175	S/CO ON 353°
100102	1750 60 18.056S 032 06.652I	5199	S/B ENG'S
100102	1808 60 15.137S 032 06.637I	5186	LET GO XBT
100102	1819 60 14.078S 032 06.598I	5155	PROTON SURVEY STARTED
100102	1918 60 01.884S 032 06.652I	5296	SUNSET & PUT ON REGULATION LIGHTS
100102	1925 59 59.976S 032 06.795I	5289	A/CO TO 017°
100103	46 58 40.719S 032 49.013I	5358	SUNRISE & TURNED OFF REGULATION LIGHTS
100103	250 58 10.267S 033 07.612I	5380	S/B ENG'S
100103	250 58 10.259S 033 07.617I	5380	USED ENG'S VAR'LY
100103	250 58 10.238S 033 07.627I	5379	USED HELM VAR'LY
100103	300 58 08.358S 033 08.075I	5493	8 SHAPE ROTATION RIGHT TURNING STARTED
100103	310 58 08.687S 033 08.112I	5382	8 SHAPE ROTATION LEFT TURNING STARTED
100103	320 58 08.691S 033 08.182I	5375	8 SHAPE ROTATION FINISHED
100103	324 58 08.105S 033 08.381I	5381	S/CO ON 017°
100103	336 58 05.475S 033 09.901I	5370	R/UP ENG'S
100103	520 57 40.274S 033 24.827I	5389	S/B ENG'S
100103	530 57 38.431S 033 25.983I	5404	LET GO XBT
100103	556 57 34.263S 033 28.575I	5406	R/UP ENG'S
100103	1718 54 42.824S 035 05.556I	5106	S/B ENG'S
100103	1734 54 40.154S 035 07.218I	5107	LET GO XBT
100103	1752 54 37.425S 035 09.002I	5081	R/UP ENG'S
100103	1824 54 29.408S 035 13.130I	5022	SUNSET & PUT ON REGULATION LIGHTS
100104	12 53 00.884S 035 59.899I	4676	A/CO TO 000°
100104	118 52 42.786S 035 59.724I	4773	SUNRISE & TURNED OFF REGULATION LIGHTS
100104	333 52 06.682S 035 59.711I	4906	A/CO TO 333°
100104	518 51 42.556S 035 39.372I	5131	S/B ENG'S
100104	534 51 40.286S 035 37.468I	4913	LET GO XCTD
100104	541 51 39.997S 035 37.273I	4855	LET GO XBT
100104	603 51 37.140S 035 35.055I	4944	R/UP ENG'S
100104	1247 50 06.310S 034 20.692I	5508	S/B ENG'S
100104	1753 49 03.181S 033 30.030I	0	SUNSET & PUT ON REGULATION LIGHTS

100104	2208 48 12.513S 032 50.721I	4483	USED HELM VAR'LY
100105	201 47 29.034S 032 08.613I	2693	SUNRISE & TURNED OFF REGULATION LIGHTS
100105	506 46 51.242S 031 44.542I	3694	A/CO TO 321°
100105	620 46 38.650S 031 29.915I	4758	USED ENG'S VAR'LY
100105	631 46 37.395S 031 28.271I	4499	LET GO XBT
100105	1751 44 27.484S 029 03.723I	5522	SUNSET & PUT ON REGULATION LIGHTS
100105	1818 44 22.188S 028 57.858I	5481	USED ENG'S VAR'LY
100105	1835 44 20.354S 028 55.797I	5561	LET GO XCTD
100105	1844 44 19.972S 028 55.332I	5494	LET GO ARGO FLOAT
100106	240 42 49.788S 027 16.643I	5018	SUNRISE & TURNED OFF REGULATION LIGHTS
100106	500 42 23.007S 026 47.652I	4494	A/CO TO 000°
100106	600 42 08.103S 026 47.365I	3917	A/CO TO 350°
100106	620 42 03.142S 026 46.249I	3795	USED ENG'S VAR'LY
100106	633 42 01.032S 026 45.666I	3690	LET GO XBT
100106	1748 39 45.412S 025 57.919I	2389	SUNSET & PUT ON REGULATION LIGHTS
100106	1859 39 30.016S 025 52.045I	2355	USED ENG'S VAR'LY & USED HELM VAR'LY
100106	1900 39 29.937S 025 52.014I	0	8 SHAPE ROTATION RIGHT TURNING STARTED
100106	1910 39 29.885S 025 52.100I	2355	8 SHAPE ROTATION LEFT TURNING STARTED
100106	1920 39 29.836S 025 52.128I	2356	8 SHAPE ROTATION TURNING FINISHED
100107	304 37 37.848S 025 21.911I	3479	SUNRISE & TURNED OFF REGULATION LIGHTS
100107	335 37 29.997S 025 19.169I	0	ENTETED EEZ OF SOUTH AFRICA
100107	540 36 59.055S 025 06.606I	0	A/CO TO 283°
100107	642 36 56.188S 024 49.996I	0	CHANGED ENG'S TO S/M
100107	1753 36 39.800S 022 23.755I	0	SUNSET & PUT ON REGULATION LIGHTS
100107	1801 36 39.891S 022 21.893I	0	A/CO TO 270°
100108	328 36 39.682S 020 22.693I	0	SUNRISE & TURNED OFF REGULATION LIGHTS
100108	1357 36 45.451S 018 39.602I	0	A/CO TO 000°
100108	1806 35 59.584S 018 49.740I	0	SUNSET & PUT ON REGULATION LIGHTS
100109	222 34 38.177S 018 37.976I	0	USED HELM VAR'LY
100109	342 34 24.486S 018 29.658I	0	SUNRISE & TURNED OFF REGULATION LIGHTS
100109	400 34 22.888S 018 25.249I	0	S/CO ON 304°
100109	431 34 18.816S 018 18.210I	0	A/CO TO 334°
100109	508 34 11.467S 018 13.419I	0	A/CO TO 008°
100109	558 34 00.889S 018 14.999I	0	USED HELM VAR'LY

## 6. Explanatory notes

### 6.1. Research Vessel Hakuho-Maru

The Hakuho Maru (Japan Agency for Marine-Earth Science and Technology (JAMSTEC)) is equipped with the most up-to-date facilities for research in physical oceanography, chemical oceanography, marine biology, marine geology and geophysics, and fisheries, as well as the deck machinery for handling large observational tools and sampling gears. Main winches are housed under the working deck. The propulsion is dual with Diesel CPP and electric motor drives, which enables a cruising speed of 16 knot and precise maneuvering with use of bow and stern thrusters. Particulars of the Hakuho Maru are as follows:

Keel laid	9.May.88	Research equipment
Launching	28.Oct.88	7 Winches (swell compensator for Nos. 1 & 2 Winches)
Completion	1.May.89	No.1 Winch: 14f x15,000 m
Length (overall)	100.00 m	No.2 Winch: 8.15f x12,000 m (Titanium armoured)
Length (p.p.)	90.00 m	No.3 Winch: 6.4f x12,000 m (Titanium)
Breadth (molded)	16.20 m	No.4, 5, 7, 8 Winches
Depth (molded)	8.90 m	10 Laboratories
Gross tonnage (JG)	3,987 T	No.1 & 3: Dry lab., No.2: RI lab., No.7: Wet lab.
Propulsion system	diesel/electric-motor driven	No.4: Clean room, No.5 & 6: Semi-dry lab.
Main engine	1,900 ps x 4 sets	No.10: Cold lab, etc.
Prop. Generator	1,085 kw x 2 sets	11 ton gantry
Twin propellers, twin rudders		11 ton beam crane & 3 ton deck crane
Main generator	715 KVA x 3 sets	Instruments
Bow thruster	4.2 T x 2 sets	Seabeam, Subbottom profiler,
Stern thruster	6.8T x 1 set	Oceanfloor imaging system,
Cruising speed	16.0 kn	Air gun compressor,
Endurance	12,000 n.m.	Marine meteorological observation system,
Complement	89 (include. sci. 35)	Acoustic biomass investigation system,
Builder		Meteorological satellite receiving system,
Shimonoseki Shipyard & Engine Works		CTD/DO, Precise gyrocompass,
Mitsubishi Heavy Industries, Ltd.		Data processing system, etc.



Leave Tokyo Port on Nov. 6, 2009.

## 6-2. Sampling

### 6-2-1. Water sampling

#### 6-2-1-1. CTD Carousel multi sampling (CTD-CMS)

##### CTD-hydrocast group

The CTD-CMS (CTD-Carousel Multi Sampling System) used during the KH-09-5 cruise consists of the following instruments.

CTD fish (Seabird, Model SBE-9-plus, 6800m) with a DO sensor (Seabird, SBE-43)

Carousel sampling system (Seabird, SBE-32)

24 Niskin-X bottles (General Oceanics, 12-liter type)

Turbidity meter (SeaPoint) ----- only for the Leg-1 & 2

Fluorometer (Chelsea, Aquatracka Mk III)

Pinger (Benthos, Model BFP-312) ----- only for the Leg-1 & 2

Altimeter (Benthos, Model PSA-916)

DO sensor (JFE ALEC, Model RINKO-III) ----- only for the Leg-3

The CTD-CMS system, attached at the end of the titanium armored cable (8mm o.d.) from the No.2 winch of R.V. *Hakuho Maru*, was controlled on board the ship by a CTD deck unit (Seabird, Model 11plus) connected with a WINDOWS desktop computer. The Carousel array frame has a capability to hold 24 Niskin bottles with a volume of 12 liters. A pinger and an altimeter were installed on the frame to monitor the distance above the sea bottom. During the hydrocasts, the ship stayed at a fixed position, and the system was lowered down to a depth of ~10 m above the bottom. Water samples were taken by triggering the Niskin-X bottles at appropriate depths while the system was coming up to the surface.

In order to reduce the contamination level as low as possible, all the Niskin-X bottles were cleaned on Nov. 7-9, 2009, on the ship by filling the bottles with 1.5% Extran MA01 (1 day), 0.1M HCl (pH=1, 1day), and Milli-Q water (more than 2 days), successively. Teflon spigots were pre-washed by soaking in 1% of Extran MA02 (1 day) and 1M HCl(1 day). The spigots were cleaned by heating in conc.HClO<sub>4</sub>:conc.H<sub>2</sub>SO<sub>4</sub>:conc.HNO<sub>3</sub>=1:1:1 mixture (120°C, 3 hrs), 6M HCl (120°C, 3 hrs), and Milli-Q water (100°C, 3 hrs), successively. Viton O-rings were pre-washed by soaking in 1% of Extran MA02 (1 day) and 0.1M HCl (1 day). The O-rings were cleaned by heating in 0.1M HCl (at 60°C, 12hrs), and Milli-Q water (at 68°C, 12 hrs).

All the Zn anode on the Carousel frame (except for those on the CTD housings) were replaced by Aluminum anode before the cruise, in order to avoid Zn contamination.

Collected samples were separately distributed to sub-samples for routine analyses of salinity, dissolved oxygen, pH, nutrients (Si, PO<sub>4</sub>, NO<sub>2</sub>, NO<sub>3</sub>, NH<sub>4</sub>), and chlorophyll-a. In addition to these routine measurements, various chemical components were or will be measured on board the ship or in shorebased laboratories in charge. Their brief reports on objectives and methods are shown in the following chapters.

According to a GEOTRACES recommendation, sub-sampling for trace element analyses was done inside a clean space, called “BUBBLE”, in the 7<sup>th</sup> laboratory on board the ship. This space has a volume of about 10 m<sup>3</sup> (2500 x 2000 x 2000), into which clean air is introduced from outside through two HEPA filter units. Up to 8 Niskin-X bottles can be hold vertically on a wooden frame in the BUBBLE. Compressed clean air was provided from the top air vent of each Niskin-X bottle in order to take filtrated seawater samples inside the BUBBLE.

### 6-2-1-2. Hydrocasts using Kevlar wire

#### Kevlar-wire hydrocast group

For a comparison of trace metal clean sampling, we collected seawater samples with X-type Niskin samplers attached Kevlar wire. One thousand five hundreds of the Kevlar wire (6mm $\phi$ , Hikari-kogyo) was loaded in the No. 5 winch of R.V. *Hakuho Maru*. Six Niskin samplers were attached to the Kevlar wire and closed with Teflon messengers. Seawater samples were collected at the depths of 20 m, 100 m, 200 m, 400 m, 600 m and 1000 m at stations ER-3 and 10. Three depth sensors (Alec Electronics) were attached to the samplers (200m, 400m, 1000m). After sampling, the Niskin samplers were brought into the “Bubble”, and then the seawater samples were filtered in a clean condition.



## 6.2.2. Large volume water sampling system

### Large volume water sampling group

There is an increasing need for the collection of large volume seawater samples from all depths for the determination of trace elements, isotopes, and natural and artificial radio-nuclides. During the KH04-5 cruise large volume water sampling was carried out as follows.

Large volume (250 ℓ) surface seawater samples were obtained from the pumping system of R.V. Hakuho-Maru. About 260ℓ of seawater from a range of depths, from 10 m deep down to 5000m, were collected using a large-volume water sampler. The specially constructed large-volume water sampler (model N12-1000, Nichiyu-Giken-Kohgyo Co. Ltd., Japan; Table 1, Fig. 1) was first used on the KH96-5 cruise and is equipped with the following units: (i) four rigid-PVC (poly(vinyl chloride)) sampling tubes, each of which has a 250 ℓ nominal capacity and bears a Compact-TD sensor (ALEC) or a reversing digital thermometer and digital manometer couple in a thermometer frame, (ii) a motor-driven trigger unit for stepwise closure of sampling tube, (iii) an acoustic unit which feeds electric power to the motor-driven trigger unit on receiving an acoustic command from the ship and sends an acoustic signal back to the ship immediately after each sampling and (iv) a battery unit (24 V and 12 V). On sending an acoustic command from the ship to the sampler at the sampling depth, the acoustic unit of the sampler feeds electric power to the motor-driven trigger unit. On triggering with the motor, hinged lids, fitted with strong rubber springs and rubber gaskets, are snapped into place at each end of a sampling tube and the thermometer frame rotates. By repeating the operational procedure, four 250ℓ seawater samples per cast can be obtained.

Table 1 Specification of the large-volume water sampler used in the KH-09-5 cruise.

maximum permissible operating depth	7000 m
construction materials	frame: stainless steel (SUS304) aluminium alloy (A7075-T6) titanium alloy (TITA 1) sampling tube: rigid PVC (poly(vinyl chloride)) (482 mm i.d.)
outer dimensions	1650 mm(W)×1650 mm(D)×2571 mm(H)
weight	715 kgf(in air), 538 kgf(in water)
sampling capacity	1,000ℓ (250ℓ/tube ×4 tubes)
mode of control	controlled by acoustic transmission
trigger	motor-driven trigger
electric power supply	24V and 12V from 24 of 1.5V dry cell



Fig. 1 Photograph of the large-volume water sampler used in the KH-09-5 cruise.

### 6-2-3. Plankton Sampling

Yuko Takahashi  
Ishinomaki Senshu University

#### Norpac net sampling

Thecosome pteropods (Fig.1) play an important role in the food webs of marine ecosystems and play a key role in the cycling of carbon and carbonate in the ocean. To know abundance of pteropods and species composition of zooplankton, samplings were carried out at 4 stations (ER-11, 12, 14 and 15) using the Norpac-twin nets (mesh size 110  $\mu\text{m}$ , 330  $\mu\text{m}$ , see Fig.3) in the Southern Ocean (Table.1).

#### Culture experiment

Thecosome pteropods were collected with modified twin nets (mesh size 110  $\mu\text{m}$ , 330  $\mu\text{m}$ , see Fig.4) at 3 stations (ER-12, 14 and 15) after the Norpac net samplings to study feeding biology of pteropods in the laboratory (Table.2). Available pteropods were maintained in 1 L polycarbonate bottles under controlled conditions for a maximum of 3 days. The bottles were temperature-controlled at 5°C and slowly rotated using a roller culture apparatus (Fig.2). Discard rates of mucous webs secreted by pteropods, phytoplankton ingestion rates and elimination rates of pteropods were measured.



**Fig.1.** Pteropod (*Limacina helicina*)



**Fig.2.** Roller culture apparatus



**Fig.3.** Norpac-twin nets



**Fig.4.** Modified twin net

**Table.1.** Information of NORPAC conducted by R/V Hakuho-maru in December, 2009. – January, 2010.

Station	Position	Date	Time	Estimated depth of haul (m)	Flow count	
					110 $\mu$ m (No. 3309)	330 $\mu$ m (No. 2993)
ER-11	29 59.82 S	2009.12.22	2:58	150	1710	1660
	65 00.20 E					
ER-12	37 45.64 S	2009.12.24	21:55	150	2295	1818
	57 36.99 E					
ER-14	61 59.92 S	2009.12.30	10:30	150	1505	1745
	40 05.08 E					
ER-15	65 01.22 S	2010.01.01	13:50	200	2465	2590
	33 19.06 E					

**Table.2.** Information of culture experiments of pteropods.

Station	Position	Date	Estimated depth of haul (m)	Number of collected pteropods	Available pteropods
ER-12	37 45.64 S	2009.12.24	150	0	0
	57 36.99 E				
ER-14	61 59.92 S	2009.12.30	150	0	0
	40 05.08 E				
ER-15	65 01.22 S	2010.01.01	200	4	2
	33 19.06 E				

### **6-3. Routine analysis**

#### **6-3-1. Salinity** (Keiri Imai & Salinity group)

Salinity was measured with the Autosol (Model 8400B, Guildline Instruments Ltd., Canada) salinometer. Sampling bottles for salinity were prepared according to JGOFS protocols. The Autosol was standardized using the IAPSO standard seawater. To control air temperature, the measurement carried out in the 8<sup>th</sup> laboratory of Hakuho-Maru.

#### **6-3-2. Dissolved oxygen** (Noriko Nakayama & DO-measurement Group)

The dissolved oxygen concentrations were measured using the Winkler titration method, employing an automatic titrator (806 Titrand<sup>R</sup>; Metrohm AG). The method was followed the Dickson DOE Handbook of Methods; Version 1.01, “Determination of dissolved oxygen on sea water by Winkler titration”. The precision of O<sub>2</sub> measurements was  $\pm 0.1\%$ , as determined through replicate analyses. Standardization of sodium thiosulfate titrant was calibrated by using CSK standard of 0.0100M potassium iodate (KIO<sub>3</sub>) solution (WAKO Pure Chemical Industries, LTD., LOT No. TCK8678).

#### **6-3-3. Nutrients** (Yuzuru Nakaguchi, Makoto Takeuchi, Takuya Asatani and Yukako Yamada)

##### *6-3-3-1 Method*

An aliquots of 10 cm<sup>3</sup> were used for analysis. Nutrient analysis was based on spectrophotometric determination.

Nitrate+nitrite (Nitrite): Nitrate is reduced quantitatively to nitrite by cadmium metal in the form of an open tubular cadmium reactor (OTCR). The sample system with its equivalent nitrite is treated with an acidic sulfanilamide reagent and the nitrite forms nitrous acid which reacts with the sulfanilamide to produce a diazonium ion. N-1-naphthylethylenediamine added to the sample system then couples with the diazonium ion to produce a red azo dye (absorbance maxima at 550 nm). With reduction of the nitrate to nitrite, both nitrate and nitrite react and are measured. Without reduction, only nitrite reacts. The nitrate concentration is calculated by subtracting the nitrite concentration from the summed nitrite and nitrate concentrations.

Ammonia nitrogen: Ammonia reacts with phenol and alkaline hypochlorite to form the deep blue color compounds with an absorbance maximum at 630 nm.

Phosphate: Phosphate reacts with molybdenum (VI) and antimony (III) in an acid medium to form a phosphoantimonymolybdenum complex which is subsequently reduced by ascorbic acid to a heteropolyblue with an absorbance maximum at 880 nm.

Silicate:  $\beta$ -molybdosilicic acid is formed by the reaction of silicate with molybdate at pH of 1 to 1.8. The  $\beta$ -molybdosilicic acid is reduced by tin(II) to form molybdenum blue with an absorbance maximum at 820 nm.

#### *6-3-3-2. Apparatus*

Nutrients are analyzed by an auto analyzer SWAAT (BLTEC Japan). All analytical data (nitrate, nitrite, phosphate and silicate) were corrected by using seawater reference material of nutrients (KANISO)

#### **6-3-4. pH** (Toshitaka Gamo & pH group)

Seawater samples were collected and sealed in 100 mL dry polyethylene bottles with sufficient overflow (about 100 mL), in order to avoid exchange of CO<sub>2</sub> with the atmosphere during sampling. Samples were temporarily stored in the 6th laboratory of R/V Hakuho Maru at room temperature. The measurement was done within a day after sampling. The sample was transferred to a specially designed ~20 mL cylindrical cell (made by Dr. K. Shitashima, CRIEPI) with overflow. The cell has a double structure, the inner ~20 mL space for sample seawater and a surrounding space where 25°C-constant water is circulated to hold the temperature of the inner seawater sample at 25.0±0.1°C. Below the cell was a magnetic stirrer. The pH measurement was conducted using a Total Alkalinity Titrator ATT-05A (Kimoto Electric Co. Ltd.), which was used as a pH meter for this cruise. A pH electrode (Radiometer, pHC3006) and a temperature sensor (ATT-05) were tightly inserted into the inner space of the pH cell through two tapered joints. The pH measurement was therefore conducted in a completely closed environment with a constant temperature of 25±0.1°C.

Analysis time of each seawater sample is about 5 minutes. We used the TRIS and AMP buffers for calibration. The buffer solutions were kindly prepared by Dr. Y. Koike (Ceres, Co. Ltd) just before the cruise. The e.m.f. values (mV) of the two buffers and unknown seawater samples were converted to pH values according to the equations in the manual SOP 6 (Determination of the pH of sea water using a glass/reference electrode cell, August 30, 1996). The RSD of duplicate or triplicate analyses for surface seawater samples was less than 0.002.

**6-3-5. Chlorophyll a** (Takuhei Shiozaki, Taketoshi Kodama, Shigenobu Takeda)

The fluorometric method was used for the quantitative analysis of chlorophyll *a*. Water samples (0–200 m depths) were collected from Niskin-X bottles into 300 ml amber polyethylene bottles. Samples (290 ml) were immediately filtered through 25 mm Whatman GF/F glass fiber filters maintaining vacuum levels of 0.02 MPa or less. Filters were placed in polypropylene vials and extracted in 6.0 ml N, N-dimethylformamide. The samples are allowed to extract for 1–2 days in a freezer (–20°C). After removal from the cold, extracted samples were placed in a 13 mm glass cuvette and read on the Turner Designs 10-AU field fluorometer with a chlorophyll optical kit for the non-acidification method (Welschmeyer, 1994, Limnology and Oceanography 39, 1985–1992). The concentrations of chlorophyll *a* in the sample ( $\mu\text{g l}^{-1}$ ) were calculated from the reading using the calibration and scaling factors. The fluorometer was calibrated at the beginning of leg. 1 and the end of leg. 3 with a commercially available chlorophyll *a* standard (from *Anacystis nidulans* algae, Sigma Chemical Co.). Serial dilutions are prepared and linear calibration factors are calculated for each analytical range.

## **6-4. *In situ* measurements**

### **6-3-1. Light intensity**

Takuhei Shiozaki (Graduate School of Agricultural and Life Sciences, The University of Tokyo)

An underwater natural chlorophyll fluorescence meter with a  $4\pi$  PAR light sensor (Biospherical Instruments, model INF-300) was attached at the end of the titanium cable from the No.3 winch of R.V. *Hakuho Maru*, and PAR light intensity was measured from the sea surface to 150 m depth every 1 second (0.3 m/sec) at around noon.

The measured PAR light intensity at each depth relative to that at the sea surface was approximated to exponential curve, and depths for 50, 25, 10, and 1% light levels were estimated. The estimated layers were used for water samplings of nitrogen fixation study by Niskin-X bottles (12-liter type) on a CTD-Carousel system.

### **6-4-2. GAMOS**

Hajime Obata (Ocean Research Institute, University of Tokyo)

An in-situ flow-through chemical analyzer, “GAMOS”, was attached at the end of the titanium cable from the No.3 winch of R.V. *Hakuho Maru*. This analyzer was originally developed for a continuous measurement of dissolved manganese using a luminol-hydrogen peroxide chemiluminescence method (Okamura et al., 2001). During this cruise, subnanomolar of Fe(II) in seawater was measured from the sea surface to 1000 m depth every 1 second (1 m/sec). The details of this instrument were described in Mase et al. in this report. Briefly, the GAMOS consists of an acrylic, oil- or water-filled pressure-compensated vessel containing a flow-through analyzing system and an aluminum pressure housing for electronic modules. Seawater sample or standard solution are mixed with hydrochloric acid to acidify the pH at 6.0. The mixed solution is then mixed with a reagent (aqueous ammonia and luminol solution), and finally introduced into the CL cell through the reaction coil. The Fe(II) concentration is determined by the measurement of the CL intensity at 1 s interval.



## 6.5. Underway geophysical observations

Yoshifumi Nogi and Tomoko Hanyu

National Institute of Polar Research/The Graduate University for Advanced Studies (SOKENDAI)

### Introduction

Marine geophysical research in the Indian Ocean sector of the Antarctic Ocean is vital to understanding the process of Gondwana fragmentation and also essential for revealing change in paleoenvironment due to reconfiguration of the continents and the ocean followed by seafloor spreading. However, tectonic history in the Southern Indian Ocean still remains less well-defined because of the sparse observations in this area. Measurements of multi-narrow beam bathymetry, geomagnetic field and gravity field were carried out along the ship's tracks except for EEZ. The ship's tracks during the cruise are shown in Figure 1. Main purpose of the measurements is to reveal the seafloor spreading history after Gondwana breakup. Especially, we focused the area between south of the Southwestern Indian Ridge and off Antarctic coast where the complicated seafloor spreading evolution related to Gondwana breakup are deduced.

### Swath Bathymetry

Multi-narrow beam bathymetric data were collected using a SeaBeam 2120 along the ship's tracks during the cruise. Backscatter image were also obtained simultaneously. These data will be processed after the cruise. CTDs data during the cruise were used to estimate vertical sound velocity profiles. Measurements of XCTDs and XBTs were also done for sound velocity correction as complement of CTDs data and these are listed in Table 1. An example of swath bathymetry during the cruise around ER15 site is shown in Figure 2. Piston coring were made at ER15 site.

Date (UT)	Start time (UT)	End time (UT)	Measurements	Latitude	Longitude
27/Dec., 2009	06:44	06:50	XCTD	-49°55.5'	53°34.9'
02/Jan., 2010	18:08	18:14	XCTD	-60°14.5'	32°06.6'
03/Jan., 2010	05:30	05:35	XBT	-57°38.1'	33°26.2'
03/Jan., 2010	17:34	17:39	XBT	-54°40.2'	35°07.2'
04/Jan., 2010	05:34	05:37	XCTD	-51°40.3'	35°37.5'
04/Jan., 2010	05:41	05:46	XBT	-51°40.0'	35°37.3'
05/Jan., 2010	06:31	06:36	XBT	-46°37.4'	31°28.3'
05/Jan., 2010	18:36	18:42	XCTD	-44°20.2'	28°55.6'
06/Jan., 2010	06:33	06:38	XBT	-42°01.0'	26°45.5'

**Table 1.** List of measurements of XCTDs and XBTs during the cruise.

### Geomagnetic field

A shipboard three component magnetometer (STCM: Isezaki, 1986) and a ship-towed proton precession magnetometer were used for the measurements of the geomagnetic field during the cruise. The total intensities of the geomagnetic field were obtained along the ship's tracks by using a ship-towed proton precession magnetometer (PR-745, Kawasaki Geol. Eng. Co.). The vector geomagnetic field will be derived by STCM using deck-mounted fluxgate magnetometers (SBM-89, GAUSS) and gyros. To derive the real geomagnetic field from STCM data, twelve constants related to the ship's permanent and induced magnetic field are estimated using data from "Figure 8 turns". "Figure 8 turns" is made by steering the ship in a tight circle, both clockwise and counter clockwise rotations. "Figure 8 turns" were conducted three times during the cruise and these are listed in Table 2.3.1. An example of total intensity magnetic anomalies obtained during the cruise are shown in Figure 3.

No.	Date	Time(UT)	Latitude	Longitude
1	21/Dec., 2009	07:00-07:20	29°49.6'S	64°51.1'E
2	03/Jan., 2010	03:00-03:20	58°08.4'S	33°08.0'E
3	06/Jan. 2010	19:00-19:20	39°29.9'S	25°52.0'E

**Table 2.** List of “Figure 8 turns”

### **Gravity field**

Gravity field data were collected using a shipboard gravimeter (ZLS-D004, ZLS Co. USA). The onshore gravity field measurements by a gravimeter (Model G124, Lacoste & Romberg) were also done at Portruis and Capetown ports, and the data will be used for the correction of the instrument drift of a shipboard gravimeter.

### **The Other Underway Observations**

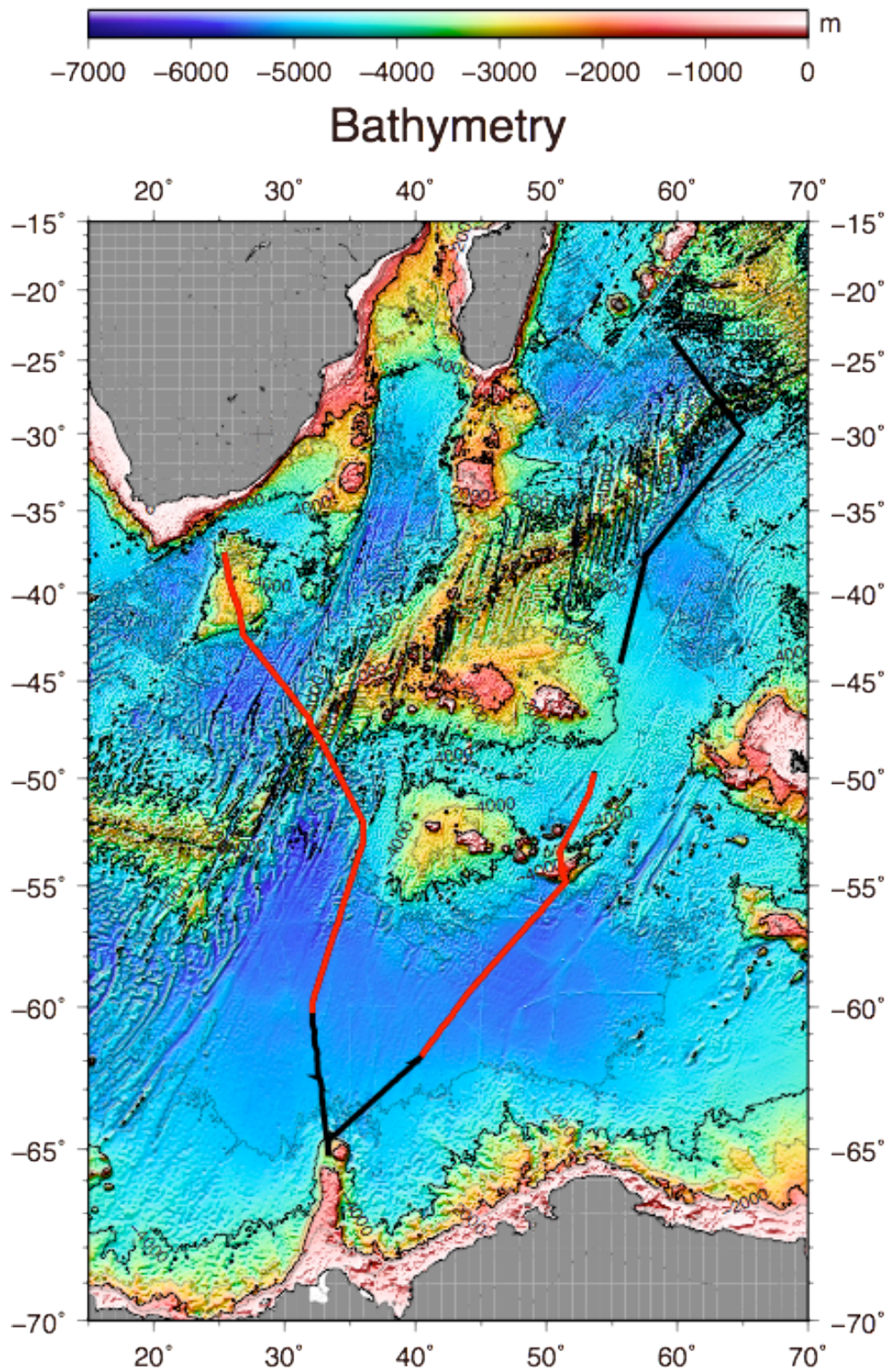
Surface water monitoring were also carried out during the cruise and those data are listed in Table3.

### **References**

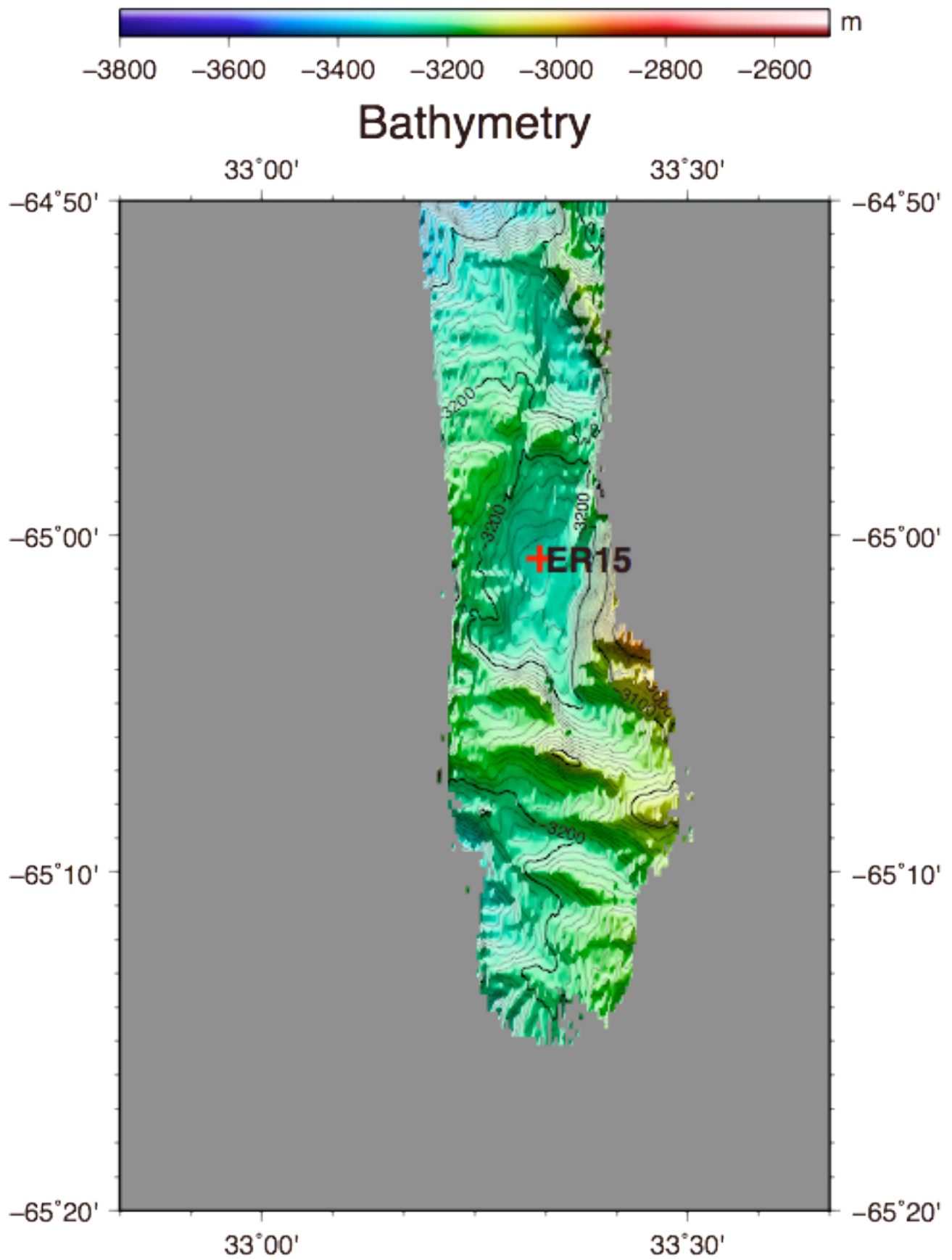
Isezaki N.,1986. A new shipboard three component magnetometer, *Geophysics*, 51, 1992-1998.

Station	Latitude			Longitude			Time	Temperature	Salinity	Chlorophyll <i>a</i>
							(UT)	°C	psu	[g/l]
1	29	- 59.82	S	64	- 59.93	E	12/22 7:02	21.9	35.360	0.05
2	30	- 59.66	S	64	- 5.17	E	12/22 12:31	20.9	35.406	0.06
3	31	- 45.24	S	63	- 23.28	E	12/22 16:05	21.3	35.356	0.06
4	32	- 41.95	S	62	- 30.31	E	12/22 20:37	19.1	35.150	0.14
5	33	- 58.62	S	61	- 17.53	E	12/23 2:52	19.2	35.281	0.08
6	35	- 13.98	S	60	- 5.70	E	12/23 8:51	18.3	35.228	0.12
7	36	- 23.68	S	58	- 57.64	E	12/23 14:28	16.9	35.262	0.24
8	37	- 45.05	S	57	- 36.92	E	12/25 5:50	17.1	35.423	0.36
9	39	- 25.85	S	57	- 6.50	E	12/25 12:53	15.2	35.374	0.82
10	40	- 35.92	S	56	- 44.86	E	12/25 17:21	15.2	35.338	0.86
11	42	- 51.84	S	56	- 1.52	E	12/26 1:38	10.7	33.980	2.30
12	43	- 52.91	S	55	- 40.91	E	12/26 6:00	10.0	34.101	1.24
13	49	- 57.29	S	53	- 34.19	E	12/27 6:58	3.9	33.522	1.79
14	51	- 6.84	S	52	- 58.22	E	12/27 11:04	3.3	33.573	1.49
15	53	- 17.95	S	51	- 10.43	E	12/27 20:58	2.5	33.579	1.64
16	54	- 10.85	S	51	- 10.17	E	12/28 0:30	1.8	33.652	0.84
17	54	- 57.53	S	51	- 18.75	E	12/28 5:41	0.9	33.707	1.07
18	55	- 59.02	S	49	- 43.97	E	12/28 10:52	0.8	33.666	1.09
19	56	- 57.38	S	48	- 10.69	E	12/28 15:48	-0.1	33.355	0.29
20	58	- 7.74	S	46	- 13.86	E	12/28 21:40	0.4	33.669	0.88
21	59	- 7.45	S	44	- 34.24	E	12/29 2:35	-0.1	33.334	0.23
22	60	- 4.70	S	43	- 5.51	E	12/29 7:14	-0.2	33.180	0.58
23	61	- 1.94	S	41	- 40.66	E	12/29 11:40	-0.6	33.311	0.59
24	61	- 59.93	S	40	- 4.52	E	12/29 16:50	-0.6	33.234	0.65
25	61	- 59.94	S	40	- 4.85	E	12/31 16:22	0.2	33.115	1.57
26	62	- 57.84	S	37	- 46.67	E	12/31 22:31	-0.6	32.977	2.46
27	64	- 15.67	S	34	- 33.08	E	1/1 5:37	-1.4	32.855	0.53
28	65	- 8.15	S	33	- 24.96	E	1/1 9:57	-1.7	33.152	0.73
29	63	- 33.25	S	32	- 54.67	E	1/2 1:57	-1.2	32.921	2.60
30	62	- 49.13	S	32	- 46.75	E	1/2 4:54	-0.9	33.042	0.65
31	61	- 37.82	S	32	- 27.70	E	1/2 12:40	0.2	32.962	1.07
32	60	- 12.46	S	32	- 6.54	E	1/2 18:34	0.4	33.278	2.15
33	58	- 8.95	S	33	- 7.92	E	1/3 3:19	0.6	33.453	7.11
34	56	- 38.32	S	34	- 6.05	E	1/3 9:45	0.5	33.375	3.28
35	55	- 33.75	S	34	- 36.98	E	1/3 13:57	1.0	33.461	2.46
36	54	- 2.88	S	35	- 27.04	E	1/3 20:10	2.2	33.567	1.91
37	51	- 45.39	S	35	- 41.77	E	1/4 5:07	2.6	33.535	1.37

**Table 3.** The location and the several surface water monitoring data of the under way sampling

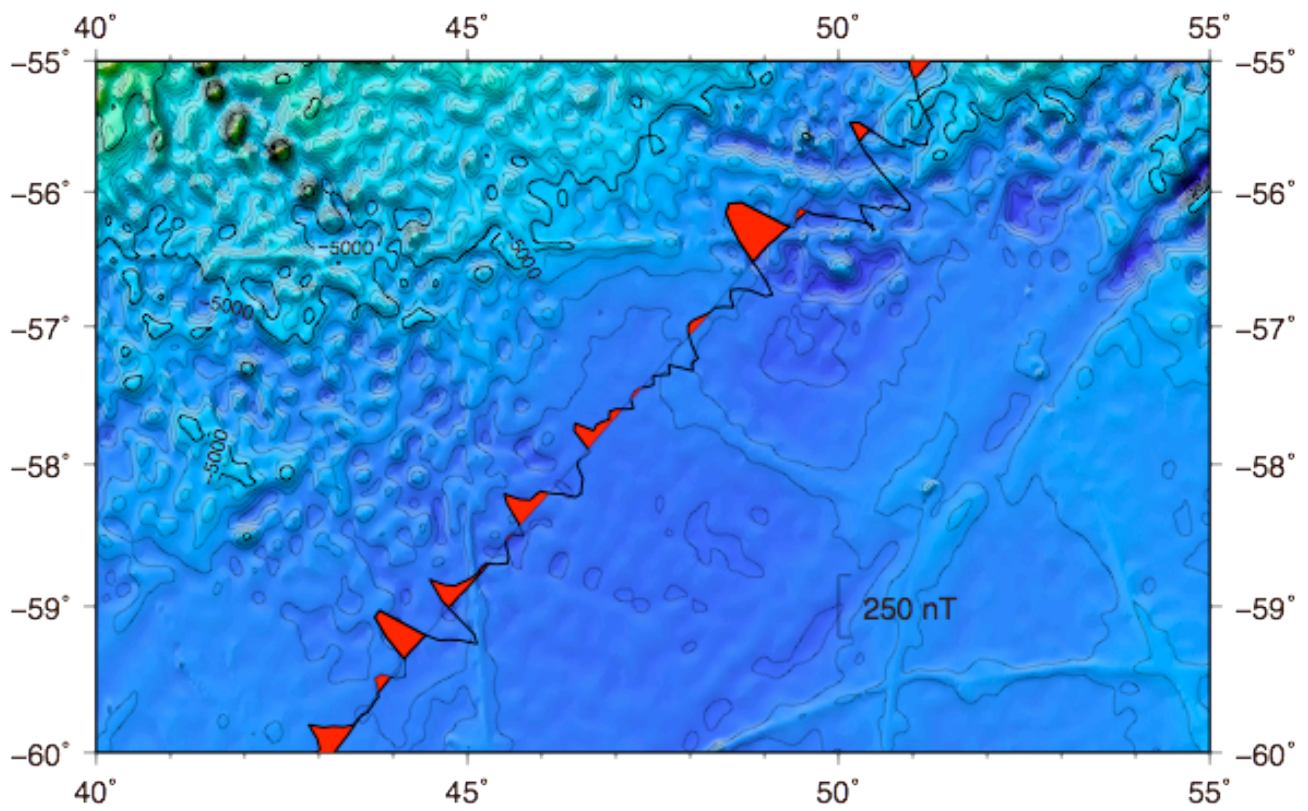


**Fig. 1** Observation lines during the cruise. Swath bathymetry, gravity and vector geomagnetic field measurements were conducted along the ship's track (solid lines). Red lines indicate the observation lines where the total intensities of the geomagnetic field measurements by using a ship-towed proton precession magnetometer were also carried out.



**Fig. 2** Example of swath bathymetry data obtained during the cruise around ER15 site.





**Fig. 3** Example of total intensity magnetic anomalies along the ship's track. Positive magnetic anomalies are in red.

## 6.6. Argo float deployment in the South Indian Ocean

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Technology

In order to build a real-time monitoring system of subsurface temperature and salinity, an international project called Argo, which aims to deploy roughly 3000 profiling floats over the global oceans, started in 2000 (Argo Science Team, 2001). Argo floats drift freely at a predetermined parking depth (typically 2000 dbar), and make an ascent to the sea surface at a predetermined interval (typically 10 days), by increasing the volume of the external hydraulic bladder and thus increasing the buoyancy. During the ascent, they measure temperature, conductivity, and pressure with the CTD sensor. The collected data are transmitted to satellites. After relevant quality control is made, the data are in almost real time provided to meteorological organizations, research institutes, and universities via Global Data Assembly Center (GDAC: <http://www.usgodae.org/argo/argo.html>, <http://www.coriolis.eu.org/>) and Global Telecommunication System (GTS). These data are utilized for analysis and forecasts of sea conditions.

In this cruise, 3 Argo floats were deployed in the Southern Indian Ocean, where the float density is low. The status of floats and their launches are shown in Table 1.

Table 1 Status of floats and their launches

Float

Float Type	APEX floats manufactured by Webb Research Ltd.
CTD sensor	SBE41 manufactured by Sea-Bird Electronics Inc.
Cycle	10 days (approximately 9 hours at the sea surface)
ARGOS transmit interval	30 sec
Target Parking Pressure	1000 dbar
Sampling layers	110 (1950, 1900, 1850, 1800, 1750, 1700, 1650, 1600, 1550, 1500, 1450, 1400, 1350, 1300, 1250, 1200, 1150, 1100, 1050, 1000, 975, 950, 925, 900, 875, 850, 825, 800,

	775, 750, 725, 700, 675, 650, 625, 600, 580, 560, 540, 520, 500, 490, 480, 470, 460, 450, 440, 430, 420, 410, 400, 390, 380, 370, 360, 350, 340, 330, 320, 310, 300, 290, 280, 270, 260, 250, 240, 230, 220, 210, 200, 195, 190, 185, 180, 175, 170, 165, 160, 155, 150, 145, 140, 135, 130, 125, 120, 115, 110, 105, 100, 95, 90, 85, 80, 75, 70, 65, 60, 55, 50, 45, 40, 35, 30, 25, 20, 15, 10, 4 dbar)
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#### Launches

Float S/N	ARGOS ID	Date and Time of Reset	Date and Time of Launch	Location of Launch	CTD St. No.
3549	76304	2009/12/22 06:19 (UTC)	2009/12/22 07:39 (UTC)	30-00.1S 64-59.5E	ER-11
3547	76302	2009/12/25 05:27 (UTC)	2009/12/25 06:20 (UTC)	37-45.4S 57-36.8E	ER-12
3511	76263	2010/01/05 17:04(UTC)	2010/01/05 18:44(UTC)	44-20.00S 28-53.5E	

Argo Science Team (2001) Argo: The global array of profiling floats. P. 248-258, In Observing the Oceans in the 21st Century, ed. By C. J. Koblinsky and N. R. Smith, GODAE Project Office, Bureau of Meteorology, Melbourne.



## 7. Routine data for the CTD hydrocsst samples

Lat. 8 31.1 S Long 86 1.55 E																														
Station ER-2 (08°31.10'N, 86°01.55'E; D(S)=3,680 m); Nov. 17, 2009, 15:01 ~ Nov. 18, 2009, 14:19; Bottom altitude: 15 m)																														
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF
5	ER0150	25	0	0.0	29.5				34.506	1	120.37		1	0.17	1	0.01		1	0.026	1	0.64		1	0.04		1	0.52	4		
5	ER0135	10	11	11.3	28.837	28.834	21.840	34.624	34.624	1	202.92	198.59	1	0.22	1	0.03	0.03	1	0.016	1				0.12	0.11	1	0.09	4		
5	ER0133	8	26	26.1	28.7145	28.708	21.918	34.673	34.747	4	201.85	197.52	1	0.50	1	0.22	0.21	1	0.037	1				0.14	0.13	1	0.20	4		
4	ER0116	16	40	40.0	28.9948	28.985	22.210	35.185	35.197	4	201.29	196.92	1																	
5	ER0130	5	51	50.9	28.2601	28.248	22.490	35.232	35.185	4	178.09	174.17	1	0.55	1	2.87	2.80	1	0.505	1				0.35	0.34	1	0.15	4		
4	ER0113	13	89	89.7	22.6918	22.674	23.941	34.884	34.881	1	39.04	38.13	1			21.12	20.62	1	0.042	1	7.99	7.81	1	1.52	1.49	1	0.15	4		
5	ER0127	2	100	100.5	21.3096	21.290	24.302	34.850	34.850	1	6.06	5.92	1	0.06	1	25.09	24.50	1	0.026	1	13.31	12.99	1	1.87	1.83	1	0.11	4		
4	ER0109	9	150	150.9	16.6386	16.614	25.557	34.936	34.935	1	20.93	20.41	1	0.01	1	28.27	27.57	1	0.016	1	18.21	17.76	1	2.01	1.96	1	0.20	4		
4	ER0104	4	199	200.2	14.5686	14.539	26.074	35.002	34.998	1	12.85	12.52	1			30.49	29.71	1	0.016	1	22.79	22.21	1	2.21	2.15	1	0.22	4		
3	ER0083	8	398	400.5	10.7374	10.688	26.866	35.043	35.041	1	12.78	12.45	1			34.96	34.05	1	0.016	1	31.31	30.49	1	2.48	2.42	1	0.33	4		
3	ER0081	6	597	600.7	9.1998	9.132	27.110	35.017	35.014	1	44.85	43.66	1			36.33	35.37	1	0.011	1	46.63	45.40	1	2.64	2.57	1	0.12	4		
3	ER0079	4	795	800.7	7.8998	7.816	27.286	34.981	34.979	1	31.74	30.89	1			36.85	35.87	1	0.026	1	58.27	56.73	1	2.69	2.62	1	0.10	4		
3	ER0077	2	992	999.9	6.8223	6.725	27.411	34.941	34.940	1	44.47	43.28	1			37.22	36.22	1	0.021	1	72.59	70.65	1	2.73	2.66	1	0.45	4		
2	ER0057	7	1240	1250.4	5.7153	5.602	27.522	34.897	34.895	1	62.29	60.62	1			37.27	36.27	1	0.026	1	85.32	83.04	1	2.73	2.66	1	0.03	4		
2	ER0055	5	1486	1499.9	4.5653	4.439	27.623	34.854	34.852	1	81.20	79.02	1			37.20	36.20	1	0.026	1	97.18	94.56	1	2.73	2.66	1	0.06	4		
2	ER0053	3	1979	2000.2	2.8831	2.733	27.738	34.785	34.781	1	117.45	114.28	1			36.22	35.24	1	0.021	1	116.40	113.26	1	2.60	2.53	1	0.11	4		
2	ER0051	1	2472	2500.8	2.1352	1.952	27.776	34.752	34.751	1	137.83	134.10	1			35.40	34.44	1	0.026	1	133.53	129.92	1	2.52	2.45	1	0.01	4		
1	ER0030	5	2963	3001.1	1.7443	1.522	27.796	34.735	34.733	1	154.32	150.14	1			35.01	34.06	1	0.026	1	133.11	129.51	1	2.46	2.39	1	0.03	4		
1	ER0028	3	3453	3500.8	1.4774	1.211	27.809	34.724	34.722	1	162.89	158.48	1			34.95	34.01	1	0.026	1	127.96	124.49	1	2.44	2.37	1	0.47	4		
1	ER0026	1	3653	3705.6	1.4443	1.158	27.811	34.722	34.721	1	155.04	150.85	1			35.10	34.15	1	0.026	1	135.53	131.86	1	2.44	2.37	1	0.42	4		

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Station ER-3 (00°00.34'S, 80°00.38'E; D(S)=4,659 m); Nov. 20, 2009, 17:14 ~ Nov. 21, 2009, 22:01; Bottom altitude: 15 m)																															
Lat. 0 0.34 S Long 80 0.38 E																															
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF	
6	ER0325	25	0	0.0	28.2000				35.365	1	202.85		1	0.19	1	0.07		1	0.008	1	0.21		1	0.14		1	0.08	4			
6	ER0319	19	11	11.2	28.3579	28.355	22.548	35.356	35.357	1	201.63	197.18	1	0.19	1				0.083	1				0.12	0.11	1	0.08	4			
6	ER0316	16	26	26.5	28.3595	28.353	22.549	35.356	35.360	1	201.63	197.18	1	0.22	1				0.083	1				0.12	0.11	1	0.06	4			
6	ER0309	9	51	51.4	28.2103	28.198	22.644	35.415	35.419	1	196.74	192.39	1	0.44	1	0.04	0.04	1	0.075	1				0.16	0.16	1	0.09	4			
5	ER0297	22	70	70.2	28.1313	28.115	22.693	35.444	35.447	1	197.89	193.50	1	0.44	1	0.35	0.34	1	0.083	1				0.19	0.18	1	0.23	4			
6	ER0302	2	100	100.6	27.9300	27.906	22.745	35.422	35.421	1	191.67	187.40	1	0.29	1	1.22	1.19	1	0.142	1				0.23	0.23	1	0.20	4			
5	ER0286	11	149	150.3	16.4975	16.473	25.817	35.231	35.239	1	80.96	78.92	1	0.03	1	23.99	23.38	1	0.075	1	7.04	6.87	1	1.75	1.71	1	0.14	4			
5	ER0278	3	202	202.9	13.7522	13.723	26.353	35.139	35.141	1	74.43	72.52	1	0.01	1	28.05	27.33	1	0.067	1	10.29	10.03	1	2.04	1.98	1	0.11	4			
4	ER0267	17	399	401.8	10.7744	10.725	26.832	35.008	35.010	1	74.87	72.92	1			33.44	32.57	1	0.058	1	16.38	15.95	1	2.34	2.28	1	0.09	4			
4	ER0258	8	597	601.3	9.4128	9.344	27.069	35.009	35.010	1	60.09	58.50	1			37.82	36.82	1	0.058	1	29.02	28.26	1	2.83	2.76	1	0.10	4			
5	ER0291	16	717	722.3	8.3343	8.257	27.236	35.000	35.002	1	46.74	45.50	1			39.67	38.62	1	0.092	1	27.07	26.35	1	3.02	2.94	1	0.13	4			
4	ER0252	2	801	806.6	7.7881	7.705	27.312	34.992	34.990	1	47.75	46.48	1			41.08	39.99	1	0.050	1	47.74	46.47	1	3.16	3.07	1	0.07	4			
3	ER0241	16	993	1001.4	6.4688	6.374	27.451	34.933	34.932	1	59.35	57.76	1			42.30	41.17	1	0.050	1	62.28	60.62	1	3.18	3.10	1	0.10	4			
3	ER0235	10	1241	1251.2	5.2148	5.106	27.562	34.873	34.884	4	80.88	78.71	1			42.34	41.21	1	0.042	1	73.90	71.92	1	3.21	3.12	1	0.06	4			
3	ER0227	2	1490	1503.3	4.1852	4.063	27.647	34.834	34.870	4	97.69	95.06	1			41.89	40.76	1	0.042	1	83.29	81.04	1	3.18	3.10	1	0.05	4			
2	ER0218	18	1980	2000.8	2.5790	2.433	27.752	34.770	34.771	1	136.92	133.22	1			38.73	37.68	1	0.042	1	100.61	97.89	1	2.99	2.91	1	0.11	4			
2	ER0212	12	2473	2501.4	2.0302	1.849	27.780	34.746	34.746	1	155.82	151.61	1			39.89	38.81	1	0.033	1	106.46	103.58	1	2.90	2.82	1	0.12	4			
2	ER0203	3	2965	3002.8	1.7225	1.500	27.796	34.733	34.734	1	165.79	161.30	1			39.64	38.57	1	0.033	1	112.66	109.62	1	2.85	2.78	1	0.14	4			
1	ER0196	21	3453	3500.9	1.5047	1.238	27.808	34.725			171.06	166.44	1			39.61	38.54	1	0.017	1	120.87	117.60	1	2.85	2.78	1	0.08	4			
1	ER0189	14	3941	4000.1	1.3982	1.082	27.815	34.721	34.720	1	179.71	174.85	1			37.88	36.86	1	0.017	1	122.63	119.32	1	2.81	2.73	1	0.10	4			
1	ER0184	9	4429	4500.7	1.4126	1.040	27.817	34.719	34.720	1	184.18	179.19	1			38.96	37.91	1	0.017	1	125.68	122.28	1	2.78	2.71	1	0.06	4			
1	ER0177	2	4652	4730.0	1.4291	1.029	27.817	34.719	34.720	1	185.34	180.32	1			36.24	35.26	1	0.008	1	127.65	124.19	1	2.78	2.71	1	0.03	4			

## Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Station ER-5 (16°44.58'N, 68°59.72'E; D(S)=3,624 m); Nov. 29, 2009, 11:19 ~ Nov. 30, 2009, 09:31; Bottom altitude: 14.5 m)																															
									Lat		16		44.58 S		Lon		68		59.72 E												
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF	
6	ER0500	25		0.0	28.9	28.900	22.777	35.901	35.901	1	203.64	199.10	1	0.36	1														8.104	1	
6	ER0486	11	10	10.2	28.1257	28.123	23.032	35.899	35.969	4	202.79	198.22	1	0.44	1										0.23	0.23	1	0.00	4	8.113	1
6	ER0483	8	24	24.6	28.2698	28.264	23.142	36.106	36.365	4	199.66	195.15	1	0.55	1							0.08	0.07	1	0.12	0.11	1	0.11	4	8.119	1
6	ER0480	5	49	49.6	28.1762	28.164	23.616	36.692	36.616	4	168.57	164.68	1	0.55	1	1.74	1.70	1	0.475	1	0.02	0.02	1	0.37	0.37	1	0.06	4	8.058	1	
5	ER0459	9	60	60.5	26.1161	26.102	24.130	36.493	35.126	4	139.67	136.38	1	0.43	1	5.43	5.31	1	1.525	1	1.46	1.43	1	0.58	0.57	1	0.14	4	7.980	1	
5	ER0456	6	80	80.7	20.6298	20.615	24.932	35.437	35.424	4	14.28	13.93	1			24.59	23.99	1			15.14	14.78	1	1.80	1.76	1	0.06	4	7.670	1	
5	ER0464	14	99	100.1	19.8821	19.864	25.317	35.679	35.677	1	6.78	6.61	1	0.03	1	24.92	24.31	1			17.56	17.13	1	2.06	2.01	1	0.02	4	7.636	1	
5	ER0453	3	150	150.9	17.0155	16.990	25.933	35.541	35.536	1	3.06	2.99	1	0.07	1	22.21	21.65	1	5.100	1	22.13	21.57	1	2.27	2.21	1	0.11	4	7.562	1	
4	ER0437	12	200	201.3	15.3544	15.323	26.272	35.482	35.489	4	2.10	2.05	1	0.07	1	22.55	21.97	1	4.250	1	25.29	24.64	1	2.32	2.26	1	0.13	4	7.525	1	
4	ER0433	8	398	400.4	12.7751	12.720	26.938	35.630	35.627	1	2.09	2.03	1			27.12	26.40	1	1.350	1	34.80	33.88	1	2.55	2.48	1	0.24	4	7.497	1	
4	ER0429	4	598	602.3	11.1691	11.092	27.170	35.528	35.529	1	3.72	3.62	1			30.90	30.09	1			48.79	47.50	1	2.76	2.69	1	0.03	4	7.493	1	
3	ER0411	11	796	802.5	9.8683	9.773	27.346	35.454	35.456	1	3.68	3.58	1			33.86	32.96	1			63.54	61.84	1	2.85	2.78	1	0.01	4	7.448	1	
3	ER0408	8	993	1001.4	8.4356	8.326	27.467	35.308	35.303	1	11.43	11.13	1			35.83	34.87	1			74.20	72.22	1	3.02	2.94	1	0.36	4	7.470	1	
3	ER0405	5	1239	1250.4	6.9168	6.791	27.576	35.162	35.161	1	26.65	25.93	1			34.35	33.43	1			88.03	85.66	1	2.64	2.57	1			7.471	1	
3	ER0403	3	1486	1500.5	5.4669	5.330	27.664	35.035	35.160	4	45.17	43.96	1			37.31	36.30	1			103.10	100.33	1	3.09	3.01	1			7.480	1	
2	ER0384	9	1980	2001.2	3.183	3.028	27.752	34.837	34.837	1	97.14	94.52	1			36.30	35.32	1			126.99	123.56	1	2.90	2.82	1	0.02	4	7.535	1	
2	ER0381	6	2471	2500.7	2.2496	2.064	27.787	34.775	34.774	1	120.03	116.78	1			35.72	34.75	1			137.42	133.71	1	2.83	2.75	1			7.558	1	
2	ER0378	3	2961	3000.3	1.839	1.614	27.799	34.748	34.748	1	131.52	127.97	1			35.63	34.66	1			142.23	138.38	1	2.76	2.69	1			7.578	1	
1	ER0358	8	3450	3499.6	1.7231	1.451	27.804	34.738	34.739	1	140.74	136.93	1			35.19	34.24	1			143.41	139.53	1	2.83	2.75	1	0.38	4	7.597	1	
1	ER0354	4	3605	3657.8	1.7149	1.426	27.804	34.737	34.737	1	141.65	137.82	1			35.53	34.57	1			143.82	139.93	1	2.81	2.73	1	0.33	4	7.598	1	

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Station ER-6 (14°00.12'N, 68°59.45'E; D(S)=4,093 m); Nov. 30, 2009, 23:02 ~ Dec. 02, 2009, 02:20; Bottom altitude: 14.6 m)																														
Lat. 14 0.12 N Long 68 59.45 E																														
Cast	Sample	Niskin	Depth (m)	Pressure	Temp. (°C)	Pot.Temp	Sigma-th	Salinity	Salinity	QF	Oxygen	Oxygen	QF	Chlorophyll a	QF	NO3+NO2	NO3+NO2	QF	NO2	QF	SiO2	SiO2	QF	PO4	PO4	QF	NH4	QF	pH	QF
No.	No.	No.		(decibar)	(CTD)			(CTD)	(Routine)		(μmol/L)	(μmol/kg)		(μg/L)		(μmol/L)	(μmol/kg)		(μmol/L)		(μmol/L)	(μmol/kg)		(μmol/L)	(μmol/kg)		(μmol/L)			
8	ER0725	25	0	0.0	28.2						199.05		1	0.13	1	0.19		1									0.31	4	8.136	1
8	ER0711	11	10	10.4	28.5306	28.528	23.215	36.319	36.359	4	199.04	194.53	1	0.12	1	0.23	0.23	1	0.075	1				0.21	0.21	1	0.19	4	8.138	1
8	ER0708	8	26	26.0	28.7128	28.707	23.413	36.662			199.09	194.54	1			0.23	0.23	1	0.050	1				0.21	0.21	1	0.17	4	8.120	1
8	ER0705	5	51	51.2	28.2752	28.263	23.524	36.614	36.613	1	191.28	186.88	1	0.36	1	0.78	0.76	1	0.375	1				0.28	0.27	1	0.25	4	8.100	1
7	ER0679	4	60	60.5	28.1212	28.107	23.559	36.591	36.564	4	185.69	181.41	1	0.43	1	1.21	1.18	1	0.675	1	0.02	0.02	1	0.33	0.32	1	0.20	4	8.083	1
7	ER0687	12	100	100.4	22.3184	22.298	24.922	36.035	36.039	1	21.98	21.45	1	0.13	1	24.07	23.49	1	0.125	1	14.65	14.29	1	1.99	1.94	1	0.25	4	7.722	1
6	ER0657	7	149	150.1	18.3597	18.333	25.768	35.754	35.744	4	3.91	3.82	1	0.05	1	20.15	19.64	1	13.875	1	20.45	19.94	1	2.50	2.44	1	0.16	4	7.586	1
6	ER0654	4	200	200.8	15.8382	15.806	26.349	35.722	35.720	1	2.51	2.44	1	0.04	1	21.43	20.88	1	7.875	1	24.16	23.54	1	2.53	2.46	1	0.22	4	7.543	1
6	ER0660	10	300	301.8	13.4313	13.389	26.716	35.518			2.52	2.45	1			26.46	25.77	1	7.325	1	28.31	27.58	1	2.55	2.48	1	0.21	4	7.505	1
5	ER0635	10	399	401.5	12.3283	12.274	26.912	35.483	35.484	1	2.84	2.76	1			30.14	29.35	1	0.025	1	33.65	32.77	1	2.74	2.67	1	0.16	4	7.501	1
5	ER0630	5	599	603.1	11.1688	11.092	27.156	35.509	35.510	1	5.10	4.97	1			32.01	31.17	1	0.025	1	46.30	45.08	1	2.90	2.82	1	0.14	4	7.504	1
4	ER0610	10	795	801.0	9.624	9.530	27.339	35.393	35.390	1	9.71	9.45	1			34.92	33.99	1	0.025	1	63.01	61.34	1	3.06	2.98	1	0.17	4	7.491	1
4	ER0607	7	992	1000.2	7.9103	7.804	27.470	35.211	35.209	1	22.36	21.76	1			36.42	35.45	1			76.52	74.48	1	3.16	3.07	1	0.14	4	7.483	1
4	ER0603	3	1242	1252.8	6.4961	6.375	27.578	35.094	35.095	1	36.96	35.97	1			36.89	35.90	1			89.32	86.92	1	3.18	3.10	1	0.12	4	7.486	1
3	ER0584	9	1489	1503.2	5.136	5.003	27.659	34.980	34.981	1	59.39	57.80	1			37.00	36.01	1			102.47	99.71	1	3.21	3.12	1	0.14	4	7.484	1
3	ER0581	6	1982	2003.2	3.1104	2.956	27.753	34.829	34.830	1	103.00	100.22	1			36.37	35.38	1			125.61	122.22	1	3.04	2.96	1	0.09	4	7.545	1
3	ER0578	3	2472	2501.5	2.2136	2.029	27.784	34.769	34.771	1	132.57	128.98	1			35.66	34.70	1			133.70	130.08	1	2.97	2.89	1	0.16	4	7.583	1
2	ER0559	9	2962	3000.4	1.819	1.595	27.799	34.745	34.747	1	151.34	147.24	1																7.603	1
2	ER0554	4	3452	3500.4	1.7206	1.448	27.803	34.738	34.739	1	158.02	153.74	1			35.19	34.24	1			134.33	130.69	1	2.90	2.82	1	0.06	4	7.616	1
1	ER0533	8	3940	4000.1	1.7147	1.389	27.806	34.736	34.736	1	146.66	142.70	1			35.78	34.82	1			141.47	137.65	1	2.97	2.89	1	0.09	4	7.619	1
1	ER0529	4	4077	4140.8	1.7289	1.387	27.806	34.736	34.734	1	145.93	141.99	1			36.01	35.04	1			139.98	136.19	1	2.95	2.87	1	0.11	4	7.619	1

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Lat. 9 59.63 N Long. 68 44.79 E																														
Station ER-7 (09°59.88'N, 68°44.79'E; D(S)=4,512 m); Dec. 02, 2009, 22:58 ~ Dec. 04, 2009, 02:04; Bottom altitude: 19 m)																														
Cast	Sample	Niskin	Depth	Pressure	Temp. (°C)	Pot.Temp	Sigma-th	Salinity	Salinity	QF	Oxygen	Oxygen	QF	Chlorophyll a	QF	NO3+NO2	NO3+NO2	QF	NO2	QF	SiO2	SiO2	QF	PO4	PO4	QF	NH4	QF	pH	QF
No.	No.	No.	(m)	(decibar)	(CTD)			(CTD)	(Routine)		(μmol/L)	(μmol/kg)		(μg/L)		(μmol/L)	(μmol/kg)		(μmol/L)		(μmol/L)	(μmol/kg)		(μmol/L)	(μmol/kg)		(μmol/L)			
8	ER0950	25	0	0.0	28.2	28.200	22.846	35.685	35.683	1	201.73	197.22	1	0.17	1	0.23	0.23	1			0.07	0.07	1	0.21	0.21	1	0.35	4	8.122	1
8	ER0938	13	10	10.0	29.0747	29.072	23.198	36.539	36.542	1	197.60	193.12	1	0.16	1	0.11	0.11	1						0.16	0.16	1	0.19	4	8.120	1
8	ER0934	9	26	25.8	29.0942	29.088	23.200	36.548	36.552	1	197.63	193.15	1	0.16	1	0.12	0.12	1						0.16	0.16	1	0.30	4	8.119	1
8	ER0931	6	50	50.7	28.9599	28.948	23.277	36.589	36.560	4	187.38	183.12	1			0.77	0.75	1						0.21	0.21	1	0.59	4	8.095	1
7	ER0905	5	60	60.2	27.555	27.541	23.632	36.442	36.353	4	132.17	129.12	1	0.33	1	6.21	6.07	1	0.825	1	1.49	1.46	1	0.68	0.66	1	0.45	4	7.981	1
7	ER0915	15	100	100.9	18.4527	18.435	25.487	35.421	35.425	1	6.24	6.08	1	0.12	1	26.75	26.08	1			17.90	17.46	1	2.20	2.14	1	0.39	4	7.607	1
7	ER0904	4	125	126.1	16.667	16.646	25.821	35.289	35.314	4	6.64	6.48	1			27.14	26.46	1			21.31	20.78	1	2.27	2.21	1	0.20	4	7.571	1
6	ER0888	13	149	150.0	15.9408	15.917	25.996	35.296	35.277	4	9.18	8.95	1	0.02	1	27.73	27.02	1			21.91	21.36	1	2.34	2.28	1	0.34	4	7.558	1
6	ER0884	9	200	200.9	13.7616	13.733	26.412	35.217	35.219	1	13.95	13.59	1	0.02	1	29.68	28.92	1			24.55	23.92	1	2.41	2.35	1	0.14	4	7.525	1
6	ER0879	4	397	399.7	11.4325	11.381	26.896	35.244	35.244	1	20.68	20.14	1			32.04	31.20	1			34.04	33.15	1	2.60	2.53	1	0.14	4	7.504	1
5	ER0863	13	597	601.5	10.2719	10.199	27.134	35.277	35.277	1	17.88	17.41	1			33.79	32.90	1			47.50	46.24	1	2.88	2.80	1	0.14	4	7.492	1
5	ER0859	9	796	801.8	8.6989	8.610	27.304	35.157	35.165	1	23.42	22.79	1			35.42	34.48	1			63.45	61.76	1	2.97	2.89	1	0.32	4	7.480	1
5	ER0855	5	995	1002.7	7.9336	7.827	27.431	35.167	35.170	1	27.43	26.70	1			36.11	35.14	1			73.80	71.83	1	3.09	3.01	1	0.41	4	7.477	1
4	ER0838	13	1240	1251.1	6.4557	6.335	27.548	35.049	35.051	1	44.67	43.47	1			36.62	35.64	1			87.86	85.51	1	3.09	3.01	1	0.13	4	7.486	1
4	ER0834	9	1489	1503.0	5.0841	4.952	27.633	34.940	34.942	1	67.84	66.02	1			36.70	35.71	1			101.47	98.74	1	3.11	3.03	1	0.23	4	7.501	1
4	ER0830	5	1977	1997.8	3.1071	2.953	27.743	34.816	34.819	1	110.98	107.98	1			35.89	34.93	1			122.32	119.02	1	3.02	2.94	1	0.09	4	7.545	1
3	ER0810	10	2472	2500.9	2.1902	2.006	27.783	34.765	34.767	1	141.11	137.29	1			35.00	34.05	1			129.15	125.66	1	2.85	2.78	1	0.07	4	7.579	1
3	ER0805	5	2965	3003.1	1.8142	1.590	27.798	34.744	34.746	1	154.82	150.64	1			34.84	33.90	1			132.95	129.35	1	2.88	2.80	1	0.07	4	7.597	1
1	ER0759	9	4427	4499.6	1.7049	1.323	27.808	34.733	34.731	1	166.20	161.70	1			34.80	33.86	1			135.23	131.57	1	2.83	2.75	1	0.05	4	7.611	1
1	ER0754	4	4496	4569.8	1.7102	1.320	27.808	34.733	34.734	1	164.33	159.88	1			35.14	34.19	1	0.025	1	136.17	132.49	1	2.85	2.78	1	0.13	4	7.613	1
2	ER0785	10	3453	3501.5	1.7106	1.439	27.804	34.738	34.738	1	161.97	157.59	1			34.67	33.73	1			134.80	131.15	1	2.81	2.73	1	0.21	4	7.606	1
2	ER0780	5	3944	4004.1	1.69	1.365	27.807	34.734	34.736	1	160.01	155.68	1			34.99	34.04	1			136.62	132.92	1	2.81	2.73	1	0.03	4	7.615	1

## Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Lat. 4 0.83 N Lon. 69 0.42 E																														
Station ER-8 (04°00.83'N, 69°00.42'E; D(S)=4,130 m); Dec. 05, 2009, 01:05 ~ Dec. 05, 2009, 12:00; Bottom altitude: 15 m)																														
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF
3	ER1050	25	0	0.0	29.7	29.700	22.197	35.488	35.488	1	201.89	197.50	1	0.12	1	0.01	0.01	1			0.01	0.01	1	0.15	0.15	1	0.02	4	8.103	1
3	ER1043	18	11	11.0	28.9325	28.930	22.445	35.473	35.477	1	202.54	198.10	1	0.11	1	0.02	0.02	1			0.43	0.42	1	0.13	0.13	1	0.06	4		
3	ER1037	12	26	26.1	28.6746	28.668	22.546	35.491	35.495	1	203.76	199.27	1	0.14	1	0.02	0.02	1			0.03	0.03	1	0.15	0.15	1	0.06	4	8.104	1
3	ER1034	9	51	51.4	28.2865	28.274	22.700	35.523	35.525	1	200.12	195.67	1	0.15	1	0.02	0.02	1	0.014	1	0.02	0.02	1	0.10	0.09	1	0.22	4	7.570	1
3	ER1027	2	101	101.6	20.1697	20.151	24.965	35.317	35.315	1	53.83	52.51	1	0.29	1	21.27	20.75	1			13.31	12.99	1	1.48	1.44	1	0.21	4	7.570	1
2	ER1011	11	199	200.1	13.2307	13.203	26.483	35.169	35.167	1	74.49	72.57	1	0.01	1	24.58	23.95	1	0.007	1	19.91	19.40	1	1.67	1.63	1	0.11	4	7.624	1
2	ER1008	8	398	400.7	10.8499	10.800	26.864	35.067	35.069	1	75.76	73.78	1			27.98	27.25	1			26.99	26.29	1	1.94	1.89	1	0.12	4	7.568	1
2	ER1005	5	795	800.7	8.6229	8.535	27.261	35.088	35.086	1	35.87	34.92	1			33.86	32.97	1			60.31	58.71	1	2.52	2.45	1	0.09	4	7.490	1
2	ER1003	3	993	1000.7	7.0901	6.990	27.438	35.023	35.024	1	41.02	39.92	1			35.07	34.13	1			78.92	76.82	1	2.71	2.64	1	0.13	4	7.478	1
1	ER0988	13	1487	1500.5	4.6244	4.497	27.633	34.874	34.877	1	87.16	84.82	1			34.67	33.74	1			102.56	99.80	1	2.65	2.58	1	0.11	4	7.518	1
1	ER0985	10	1981	2001.8	2.8096	2.660	27.745	34.787	34.788	1	130.18	126.67	1			33.68	32.77	1			120.88	117.61	1	2.50	2.43	1	0.58	4	7.557	1
1	ER0982	7	2963	3000.8	1.7881	1.564	27.798	34.742	34.744	1	161.15	156.79	1			32.72	31.84	1			132.89	129.30	1	2.42	2.36	1	0.20	4	7.601	1
1	ER0978	3	4013	4073.7	1.7215	1.388	27.806	34.735	34.737	1	165.05	160.58	1			32.91	32.02	1			135.38	131.72	1	2.40	2.34	1	0.02	4	7.563	1

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Lat. 5 16.01 S Long 67 54.25 E																														
Station ER-9 (05°16.01'S, 67°54.25'E; D(S)=3,118 m); Dec. 07, 2009, 00:57 ~ Dec. 07, 2009, 10:49; Bottom altitude: 20 m)																														
Cast	Sample	Niskin	Depth (m)	Pressure	Temp. (°C)	Pot.Temp	Sigma-th	Salinity	Salinity	QF	Oxygen	Oxygen	QF	Chlorophyll a	QF	NO3+NO2	NO3+NO2	QF	NO2	QF	SiO2	SiO2	QF	PO4	PO4	QF	NH4	QF	pH	QF
No.	No.	No.		(decibar)	(CTD)			(CTD)	(Routine)		(μmol/L)	(μmol/kg)		(μg/L)		(μmol/L)	(μmol/kg)		(μmol/L)		(μmol/L)	(μmol/kg)		(μmol/L)	(μmol/kg)		(μmol/L)			
3	ER1125	25	0	0.0	30.2	30.200	21.583	34.897	34.897	1	201.61	197.35	1	0.09	1	0.14	0.14	1	0.007	1	0.76	0.75	1	0.10	0.09	1	0.18	4	8.125	1
3	ER1118	18	10	10.4	29.066	29.063	21.959	34.885	34.885		202.40	198.05	1			0.03	0.03	1	0.007	1	1.47	1.44	1	0.02	0.02	1	0.11	4	8.127	1
3	ER1112	12	25	25.1	28.5137	28.508	22.172	34.923	34.923		204.97	200.52	1	0.13	1	0.03	0.03	1			3.44	3.37	1	0.13	0.13	1	0.09	4	8.120	1
3	ER1109	9	50	50.3	25.1204	25.109	23.529	35.290	35.294	1	194.10	189.64	1	0.43	1	0.74	0.72	1	0.029	1	3.34	3.26	1	0.35	0.34	1	0.07	4	8.037	1
3	ER1102	2	100	100.6	15.5296	15.514	26.002	35.186	35.185	1	100.76	98.21	1	0.12	1	19.56	19.07	1	0.014	1	14.95	14.57	1	1.38	1.35	1	0.06	4	7.739	1
2	ER1086	11	200	201.7	12.6523	12.625	26.494	35.034	35.033	1	94.70	92.25	1	0.01	1	23.52	22.92	1	0.007	1	20.04	19.52	1	1.65	1.61	1	0.11	4	7.669	1
2	ER1083	8	398	401.0	10.1315	10.084	26.847	34.884	34.884	1	102.44	99.76	1			27.02	26.32	1	0.007	1	26.42	25.73	1	1.86	1.82	1	0.11	4	7.625	1
2	ER1080	5	795	800.8	7.5208	7.440	27.221	34.828	34.826	1	72.66	70.74	1			32.89	32.02	1			61.67	60.04	1	2.48	2.41	1	0.09	4	7.539	1
2	ER1078	3	993	1001.2	6.0947	6.003	27.395	34.801	34.800	1	75.73	73.71	1			34.20	33.29	1			82.02	79.83	1	2.61	2.54	1	0.03	4	7.529	1
1	ER1063	13	1486	1499.8	3.9164	3.798	27.633	34.781	34.781	1	112.51	109.49	1			33.83	32.92	1			102.09	99.34	1	2.58	2.51	1	0.06	4	7.557	1
1	ER1060	10	1979	2000.0	2.7083	2.561	27.735	34.762	34.762	1	140.05	136.27	1			33.25	32.35	1			117.41	114.25	1	2.50	2.43	1	0.04	4	7.584	1
1	ER1057	7	2767	2800.5	1.7902	1.586	27.790	34.734	34.732	1	171.56	166.92	1			32.24	31.36	1			124.78	121.40	1	2.35	2.28	1	0.12	4	7.616	1
1	ER1053	3	3125	3165.7	1.7138	1.476	27.796	34.731	34.730	1	174.01	169.30	1			32.18	31.31	1			128.08	124.61	1	2.36	2.30	1	0.10	4	7.579	1

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.



										Lat.	19	59.63 S	Long.	72	32.67 E															
Station ER-10 (19°59.63'S, 72°32.67'E; D(S)=4,343 m); Dec. 10, 2009, 17:45 ~ Dec. 13, 2009, 07:25; Bottom altitude: 15 m)																														
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF
R7	ER1325	25	0	0.0	25.4	25.400	23.326	35.139	35.139	1	217.13	212.18	1	0.04	1	0.05	0.05	1	0.005	1	1.02	1.00	1	0.10	0.10	1	0.08	4	8.075	1
R5	ER1261	11	5	5.4	25.4345	25.433	23.304	35.124	35.131	1	213.73	208.87	1			0.01	0.01	1	0.015	1	1.01	0.99	1	0.08	0.08	1	0.05	4		
R7	ER1309	9	11	10.6	25.3786	25.376	23.329	35.134	35.134	1	213.26	208.40	1	0.04	1	0.01	0.01	1	0.015	1	0.91	0.89	1	0.08	0.08	1	0.04	4	8.076	1
R7	ER1304	4	25	25.3	24.966	24.961	23.496	35.186	35.181	1	222.36	217.26	1	0.04	1	0.01	0.01	1	0.015	1	1.33	1.30	1	0.08	0.08	1	0.06	4	8.073	1
R6	ER1290	15	51	51.5	23.1348	23.124	24.075	35.232	35.233	1	228.44	223.07	1	0.06	1	0.01	0.01	1	0.010	1	3.33	3.25	1	0.08	0.08	1	0.08	4	8.074	1
R5	ER1265	15	61	60.9	22.7736	22.761	24.198	35.255	35.255	1	229.53	224.11	1			0.01	0.01	1	0.015	1	1.64	1.60	1	0.08	0.08	1	0.09	4	8.076	1
R6	ER1284	9	99	99.7	21.5982	21.579	24.621	35.374	35.374	1	228.02	222.54	1	0.17	1	0.01	0.01	1	0.015	1	0.96	0.94	1	0.08	0.08	1	0.04	4	8.069	1
R6	ER1278	3	118	118.9	21.4838	21.461	24.724	35.466	35.464	1	219.31	214.02	1	0.25	1	0.01	0.01	1	0.020	1	1.27	1.24	1	0.10	0.10	1	0.04	4	8.052	1
R5	ER1260	10	150	150.7	20.664	20.635	25.101	35.666	35.666	1	203.09	198.12	1	0.22	1	1.76	1.72	1	0.080	1	1.65	1.61	1	0.21	0.21	1	0.03	4	8.011	1
R5	ER1255	5	199	200.6	19.4858	19.449	25.495	35.770	35.769	1	187.34	182.68	1	0.03	1	2.60	2.54	1	0.015	1	2.02	1.97	1	0.27	0.27	1	0.06	4	7.982	1
R4	ER1240	15	400	403.1	12.8226	12.767	26.603	35.210	35.213	1	218.21	212.55	1			9.79	9.54	1	0.010	1	4.13	4.02	1	0.72	0.70	1	0.04	4	7.856	1
R4	ER1235	10	597	601.3	9.5578	9.489	26.830	34.734	34.734	1	236.75	230.56	1			16.07	15.65	1	0.015	1	5.07	4.94	1	1.11	1.08	1	0.06	4	7.791	1
R4	ER1230	5	795	801.7	6.2818	6.208	27.107	34.470	34.472	1	187.13	182.20	1			27.66	26.93	1	0.015	1	28.20	27.45	1	1.91	1.86	1	0.03	4	7.658	1
R3	ER1215	15	992	1001.0	4.6531	4.572	27.353	34.533	34.533	1	143.11	139.30	1			32.65	31.78	1	0.010	1	63.84	62.14	1	2.36	2.30	1	0.07	4	7.580	1
R3	ER1210	10	1240	1250.9	4.321	4.221	27.496	34.665	34.665	1	119.87	116.66	1			33.84	32.94	1	0.005	1	87.01	84.68	1	2.50	2.43	1	0.04	4	7.556	1
R3	ER1205	5	1486	1500.8	3.8034	3.686	27.588	34.710	34.711	1	123.64	120.32	1			33.62	32.71	1	0.005	1	98.59	95.95	1	2.50	2.43	1	0.04	4	7.561	1
R2	ER1190	15	1979	2000.5	2.6409	2.494	27.709	34.723	34.723	1	154.86	150.68	1			32.70	31.82	1	0.005	1	108.44	105.52	1	2.40	2.34	1	0.07	4	7.596	1
R2	ER1185	10	2470	2499.6	1.8697	1.691	27.773	34.723	34.723	1	186.64	181.59	1			31.14	30.30	1	0.010	1	108.42	105.49	1	2.25	2.18	1	0.09	4	7.623	1
R2	ER1180	5	2962	3001.1	1.5698	1.351	27.800	34.724	34.725	1	191.62	186.44	1			31.21	30.37	1	0.010	1	117.45	114.27	1	2.25	2.18	1	0.05	4	7.630	1
R1	ER1165	15	3452	3502.0	1.4248	1.160	27.811	34.722	34.722	1	191.55	186.37	1			31.48	30.63	1	0.005	1	125.64	122.24	1	2.28	2.22	1	0.06	4	7.634	1
R1	ER1160	10	3941	4002.1	1.4268	1.109	27.813	34.720	34.720	1	190.53	185.38	1			31.78	30.92	1	0.005	1	128.82	125.33	1	2.30	2.24	1	0.03	4	7.635	1
R1	ER1155	5	4306	4377.0	1.463	1.103	27.813	34.720	34.719	1	190.39	185.24	1			31.72	30.86	1	0.010	1	129.88	126.36	1	2.30	2.24	1	0.03	4	7.621	1

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Station ER-11 (30°00.02'S, 64°59.93'E; D(P)=4,660 m); Dec. 21, 2009, 08:30 ~ Dec. 22, 2009, 07:06; Bottom altitude: 14.5 m)																															
Lat. 30 0.02 S Lon. 64 59.93 E																															
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF	
7	ER1674	25	0	0.0	#N/A		#N/A		35.523	1	233.27		1	0.05	1	0.05		1	0.023	1	0.09		1	0.08		1	0.05	4	8.007	1	
7	ER1662	13	10	10.0	21.0975	21.096	24.863	35.517	35.517	1	234.51	228.82	1	0.06	1	0.02	0.02	1	0.008	1	0.56	0.55	1	0.06	0.06	1	0.02	4	8.007	1	
7	ER1658	9	25	24.7	20.5243	20.520	25.008	35.502	35.504	1	236.21	230.45	1	0.05	1	0.02	0.02	1	0.008	1	0.45	0.44	1	0.06	0.06	1				8.006	1
7	ER1653	4	50	50.1	17.5602	17.552	25.825	35.577	35.574	1	255.71	249.28	1	0.09	1	0.02	0.02	1	0.008	1	0.39	0.38	1	0.10	0.10	1	0.03	4	7.990	1	
6	ER1640	16	99	99.8	15.2089	15.194	26.283	35.458	35.456	1	246.14	239.83	1	0.53	1	2.15	2.10	1	0.177	1	0.98	0.95	1	0.28	0.28	1	0.01	4	7.944	1	
6	ER1636	12	100	100.4	15.226	15.211	26.280	35.459	35.459	1	246.38	240.07	1	0.53	1	2.19	2.13	1	0.177	1	1.59	1.55	1	0.28	0.28	1				7.940	1
6	ER1632	8	125	125.5	14.7073	14.689	26.372	35.429	35.425	1	249.75	243.34	1			3.19	3.11	1	0.154	1	1.59	1.55	1	0.30	0.29	1	0.01	4	7.932	1	
6	ER1628	4	150	151.2	14.3688	14.347	26.419	35.394	35.395	1	247.32	240.96	1	0.16	1	4.20	4.09	1	0.031	1	1.24	1.21	1	0.38	0.37	1				7.918	1
5	ER1613	14	198	199.6	13.9128	13.884	26.490	35.359	35.358	1	246.74	240.37	1	0.01	1	5.77	5.62	1	0.008	1	1.89	1.84	1	0.46	0.45	1				7.902	1
5	ER1608	9	397	399.8	12.4542	12.400	26.626	35.146	35.146	1	222.81	217.03	1			10.65	10.38	1	0.008	1	2.91	2.83	1	0.69	0.67	1	10.78	4	7.856	1	
5	ER1603	4	595	600.4	11.1851	11.109	26.716	34.949	34.949	1	237.50	231.32	1			12.90	12.56	1	0.008	1	3.43	3.34	1	0.93	0.90	1				7.821	1
4	ER1588	14	794	800.6	8.6578	8.570	26.898	34.632	34.631	1	221.22	215.42	1			19.94	19.42	1	0.008	1	8.95	8.72	1	1.39	1.35	1				7.742	1
4	ER1584	10	992	1001.0	5.5807	5.493	27.143	34.403	34.401	1	209.18	203.66	1			27.60	26.87	1	0.015	1	25.13	24.46	1	1.92	1.86	1				7.651	1
4	ER1580	6	1239	1251.4	3.749	3.654	27.363	34.424	34.428	1	189.71	184.66	1			31.30	30.47	1	0.008	1	50.46	49.11	1	2.26	2.20	1	0.03	4	7.598	1	
4	ER1578	4	1485	1500.3	3.0521	2.944	27.527	34.544	34.546	1	176.88	172.14	1			32.06	31.20	1	0.008	1	68.06	66.24	1	2.30	2.24	1				7.583	1
3	ER1561	12	1976	1998.9	2.3344	2.193	27.709	34.692	34.694	1	181.85	176.95	1			31.10	30.26	1	0.008	1	92.09	89.60	1	2.24	2.18	1	0.01	4	7.605	1	
3	ER1557	8	2469	2501.0	1.987	1.806	27.768	34.726	34.729	1	182.80	177.86	1			31.16	30.32	1	0.008	1	107.20	104.30	1	2.26	2.20	1	0.03	4	7.614	1	
3	ER1553	4	2959	3000.7	1.7285	1.506	27.792	34.729	34.729	1	185.75	180.73	1			31.45	30.60	1	0.008	1	116.03	112.89	1	2.26	2.20	1				7.614	1
2	ER1536	12	3449	3500.9	1.4575	1.192	27.809	34.721			194.68	189.42	1			31.27	30.43	1	0.015	1	120.44	117.18	1	2.26	2.20	1	0.03	4	7.616	1	
2	ER1529	5	3936	3999.9	0.912	0.609	27.831	34.702	34.703	1	213.47	207.69	1			30.94	30.11	1	0.008	1	127.18	123.73	1	2.24	2.18	1	0.05	4	7.618	1	
1	ER1508	9	4423	4500.0	0.7245	0.373	27.838	34.694	34.693	1	220.65	214.68	1			30.93	30.10	1	0.015	1	128.79	125.31	1	2.22	2.16	1	0.03	4	7.620	1	
1	ER1503	4	4697	4782.0	0.7159	0.333	27.839	34.692	34.693	1	222.27	216.25	1			30.87	30.04	1	0.015	1	129.48	125.97	1	2.20	2.14	1	0.01	4	7.617	1	

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Station ER-12 (37°45.14'S, 57°37.13'E; D(P)=5,316 m); Dec. 23, 2009, 21:21 ~ Dec. 25, 2009, 06:02; Bottom altitude: 30 m)																														
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF
8	ER1874_12	25	0	0.0					35.563	1	254.52		1	0.29	1	0.04		1			1.46	1	0.14		1	0.35	4	8.015	1	
8	ER1863_12	14	10	9.8	17.7717	17.770	25.763	35.566	35.566	1	253.05	246.69	1	0.29	1	0.02	0.02	1			0.57	0.56	1	0.14	0.14	1	0.27	4	8.017	1
8	ER1858_12	9	26	26.0	17.2097	17.205	25.893	35.556	35.557	1	255.81	249.35	1	0.50	1	0.15	0.15	1	0.036	1	0.64	0.62	1	0.16	0.16	1	0.26	4	8.006	1
8	ER1854_12	5	49	49.1	16.6323	16.624	26.038	35.565	35.567	1	243.71	237.52	1	0.30	1	1.69	1.65	1	0.445	1	1.64	1.60	1	0.24	0.23	1	0.31	4	7.984	1
7	ER1835	11	50	50.5	16.6453	16.637	26.023	35.549	35.550	1	253.05	246.63	1	0.64	1	0.27	0.26	1	0.073	1	0.62	0.61	1	0.20	0.19	1	0.37	4	7.995	1
7	ER1839	15	100	100.4	16.3001	16.284	26.097	35.539	35.543	1	253.35	246.90	1	0.39	1	0.83	0.81	1	0.209	1	1.08	1.05	1	0.24	0.23	1	0.47	4	7.989	1
7	ER1829	5	149	150.6	15.8878	15.864	26.182	35.523	35.524	1	242.45	236.26	1	0.07	1	3.29	3.21	1	0.009	1	2.75	2.68	1	0.34	0.33	1	0.28	4	7.956	1
7	ER1828	4	198	199.8	15.4203	15.389	26.271	35.500	35.501	1	241.43	235.25	1	0.01	1	4.27	4.16	1	0.018	1	3.03	2.95	1	0.40	0.39	1	0.29	4	7.944	1
6	ER1813	14	398	401.1	13.7499	13.692	26.504	35.325	35.331	1	236.13	230.03	1			7.40	7.21	1	0.018	1	3.30	3.21	1	0.62	0.60	1	0.27	4	7.892	1
6	ER1808	9	595	600.1	12.2332	12.153	26.643	35.107	35.107	1	238.78	232.58	1			10.73	10.45	1	0.009	1	3.93	3.83	1	0.82	0.80	1	0.28	4	7.852	1
6	ER1803	4	793	800.0	9.9439	9.849	26.810	34.785	34.787	1	223.95	218.10	1			16.70	16.27	1	0.009	1	7.76	7.56	1	1.22	1.19	1	0.28	4	7.782	1
5	ER1787	13	990	1000.0	7.7176	7.614	26.982	34.555	34.558	1	213.73	208.11	1			22.73	22.13	1	0.009	1	15.13	14.73	1	1.62	1.58	1	0.30	4	7.711	1
5	ER1783	9	1238	1251.1	4.6551	4.552	27.237	34.384	34.386	1	209.27	203.72	1			28.95	28.18	1	0.009	1	34.53	33.61	1	2.08	2.02	1	0.31	4	7.632	1
5	ER1778	4	1485	1501.5	3.5431	3.429	27.394	34.435	34.437	1	192.85	187.71	1			31.46	30.62	1			51.79	50.41	1	2.30	2.24	1	0.34	4	7.596	1
4	ER1762	13	1779	1800.5	2.9269	2.794	27.570	34.581	34.582	1	183.01	178.10	1			31.36	30.52	1			66.37	64.59	1	2.30	2.24	1	0.28	4	7.588	1
4	ER1754	5	1977	2001.0	2.7246	2.577	27.642	34.648	34.649	1	187.42	182.38	1			30.54	29.72	1			69.54	67.67	1	2.22	2.16	1	0.31	4	7.601	1
4	ER1753	4	2465	2498.8	2.3681	2.181	27.757	34.750	34.751	1	204.63	199.10	1			28.38	27.61	1			73.68	71.69	1	2.04	1.98	1	0.32	4	7.634	1
3	ER1729	5	2957	3000.7	1.9886	1.760	27.801	34.764	34.765	1	212.37	206.62	1			28.13	27.37	1			83.95	81.68	1	1.98	1.93	1	0.32	4	7.638	1
3	ER1728	4	3445	3499.2	1.3845	1.121	27.824	34.735	34.736	1	216.16	210.31	1			29.12	28.33	1			102.16	99.40	1	2.08	2.02	1	0.34	4	7.629	1
2	ER1706	7	3933	4000.3	0.6376	0.343	27.841	34.695			224.72	218.64	1			30.38	29.56	1			125.19	121.80	1	2.20	2.14	1	0.33	4	7.614	1
2	ER1702	3	4421	4501.2	0.4591	0.116	27.844	34.683	34.683	1	228.48	222.29	1			30.83	29.99	1			132.80	129.20	1	2.24	2.18	1	0.34	4	7.612	1
1	ER1679	5	4906	5000.3	0.4713	0.072	27.845	34.681	34.681	1	229.47	223.25	1			30.93	30.10	1			133.45	129.83	1	2.20	2.14	1	0.33	4	7.609	1
1	ER1677	3	5364	5473.7	0.5115	0.054	27.845	34.680	34.680	1	229.13	222.92	1			30.92	30.08	1			132.46	128.87	1	2.24	2.18	1	0.33	4	7.597	1

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

Station ER-14 (61°59.95'S, 40°05.98'E; D(P)=5,202 m); Dec. 29, 2009, 20:53 ~ Dec. 31, 2009, 16:43; Bottom altitude: 15 m)																														
Lat. 61 59.95 S Long 40 5.98 E																														
Cast No.	Sample No.	Niskin No.	Depth (m)	Pressure (decibar)	Temp. (°C) (CTD)	Pot.Temp	Sigma-th	Salinity (CTD)	Salinity (Routine)	QF	Oxygen (μmol/L)	Oxygen (μmol/kg)	QF	Chlorophyll a (μg/L)	QF	NO3+NO2 (μmol/L)	NO3+NO2 (μmol/kg)	QF	NO2 (μmol/L)	QF	SiO2 (μmol/L)	SiO2 (μmol/kg)	QF	PO4 (μmol/L)	PO4 (μmol/kg)	QF	NH4 (μmol/L)	QF	pH	QF
8	ER2050	25		0.0					33.352	1	373.86		1	0.56	1	24.69		1	0.188	1	49.29		1	1.69		1	0.08	4	7.711	1
8	ER2039	14	9	9.5	-0.3137	-0.314	26.785	33.346	33.351	1	374.63	364.86	1	0.50	1	24.67	24.03	1	0.200	1	49.10	47.82	1	1.78	1.73	1	1.35	4	7.710	1
8	ER2034	9	25	25.1	-1.3834	-1.384	27.221	33.834	33.861	4	382.24	372.11	1	0.74	1	25.71	25.02	1	0.150	1	50.13	48.80	1	1.84	1.79	1	1.76	4	7.702	1
7	ER2011	11	44	44.7	-1.644	-1.645	27.370	34.007	34.011	1	378.93	368.84	1	1.25	1	25.94	25.25	1	0.156	1	49.31	48.00	1	1.88	1.83	1	1.72	4	7.698	1
8	ER2030	5	50	50.8	-1.7161	-1.717	27.385	34.023	34.031	1	366.07	356.31	1	1.01	1	26.96	26.24	1	0.181	1	53.25	51.83	1	1.98	1.93	1	1.75	4	7.672	1
7	ER2015	15	99	99.9	-1.0958	-1.098	27.496	34.185	34.199	4	317.96	309.45	1	0.28	1	29.29	28.50	1	0.125	1	62.04	60.38	1	2.17	2.11	1	1.11	4	7.625	1
7	ER2005	5	148	149.3	1.1519	1.145	27.644	34.513	34.516	1	215.88	210.07	1	0.02	1	31.86	31.01	1	0.013	1	81.38	79.19	1	2.40	2.33	1	1.13	4	7.562	1
4	ER1938	13	178	179.8	1.3982	1.389	27.672	34.569	34.570	1	202.23	196.78	1			31.96	31.10	1	0.013	1	84.48	82.20	1	2.40	2.33	1	1.95	4	7.554	1
7	ER2004	4	199	201.1	1.4565	1.447	27.693	34.599	34.600	1	199.82	194.44	1	0.02	1	31.85	31.00	1	0.013	1	86.42	84.09	1	2.40	2.33	1	1.14	4	7.559	1
6	ER1989	14	395	399.5	1.4811	1.461	27.768	34.694	34.695	1	200.59	195.17	1			30.52	29.70	1	0.006	1	90.78	88.33	1	2.25	2.19	1	1.21	4	7.585	1
6	ER1984	9	593	599.7	1.335	1.304	27.795	34.714	#N/A	1	206.42	200.84	1			30.00	29.19	1	0.006	1	95.92	93.33	1	2.23	2.17	1	1.11	4	7.600	1
6	ER1979	4	791	799.8	1.1407	1.099	27.810	34.715	34.716	1	209.38	203.72	1			30.01	29.19	1	0.025	1	101.74	98.99	1	2.21	2.15	1	1.19	4	7.604	1
5	ER1963	13	988	1000.4	0.9573	0.905	27.818	34.709	34.711	1	211.87	206.14	1			30.27	29.45	1	0.025	1	106.36	103.49	1	2.03	1.97	1	1.05	4	7.598	1
5	ER1959	9	1234	1249.8	0.7751	0.709	27.825	34.703	34.705	1	214.31	208.51	1			30.57	29.74	1	0.019	1	111.13	108.13	1	2.07	2.01	1	1.12	4	7.595	1
5	ER1954	4	1481	1501.2	0.6209	0.540	27.830	34.695	34.696	1	215.35	209.52	1			30.78	29.95	1	0.006	1	117.26	114.09	1	2.27	2.21	1	1.27	4	7.592	1
4	ER1930	5	1971	1999.8	0.3712	0.259	27.836	34.683	34.684	1	220.76	214.78	1			31.19	30.34	1	0.006	1	123.41	120.07	1	2.29	2.23	1	1.24	4	7.589	1
4	ER1929	4	2461	2499.7	0.1791	0.033	27.841	34.674	34.675	1	226.68	220.54	1			31.23	30.39	1	0.025	1	127.11	123.66	1	2.29	2.23	1	0.98	4	7.589	1
3	ER1905	5	2949	2999.2	0.0272	-0.157	27.846	34.667	34.668	1	234.33	227.99	1			31.15	30.31	1	0.019	1	126.60	123.17	1	2.17	2.11	1	1.49	4	7.597	1
3	ER1904	4	3439	3501.2	-0.0899	-0.316	27.849	34.662	34.662	1	241.19	234.66	1			31.08	30.24	1	0.006	1	126.45	123.02	1	2.29	2.23	1	0.56	4	7.602	1
2	ER1882	7	3926	4001.1	-0.164	-0.436	27.852	34.658	34.658	1	246.65	239.96	1			30.93	30.09	1	0.006	1	126.61	123.18	1	2.27	2.21	1	0.39	4	7.606	1
2	ER1878	3	4410	4499.5	-0.2155	-0.537	27.853	34.654	34.655	1	251.24	244.43	1			30.95	30.11	1	0.019	1	128.74	125.26	1	2.25	2.19	1	0.35	4	7.608	1
1	:R1855_1	5	4895	5000.5	-0.2362	-0.611	27.855	34.652	34.653	1	252.49	245.65	1			30.79	29.95	1	0.006	1	133.99	130.36	1	2.27	2.21	1	0.16	4	7.613	1
1	:R1853_1	3	5158	5272.2	-0.2489	-0.654	27.856	34.650	34.651	1	253.48	246.61	1			30.76	29.93	1	0.013	1	137.30	133.58	1	2.25	2.19	1	0.07	4	7.590	1

Notes:

Time is expressed as GMT.

D(S): Depth measured by Seabeam, D(P): Depth measured by PDR.

Position and depth are those when the deepest sample was taken.

Temp (°C) at Pressure zero was that of seawater obtained by bucket sampling.

## 8. Studies on seawater samples

## 8.1. Sectional distribution of trace metals (Al, Mn, Fe, Co, Ni, Cu, Zn, Cd, Pb, Zr, Nb, Hf, Ta, W, Mo, Pd, Pt, Au) and isotopes (Mo IC, W IC) in the Indian Ocean

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**Objective** The distribution of trace metals in seawater is controlled by various physical, chemical and biological processes. In order to reveal the distribution and behavior of trace metals in the oceans, we have developed multi-elemental determination of trace metals in seawater based on column concentration and detection with inductively coupled plasma mass spectrometry (Firdaus et al., 2007; Sohrin et al., 2008). In this study, we will reveal the sectional distribution of bioactive trace metals (Al, Mn, Fe, Co, Ni, Cu, Zn, Cd, Pb) and incompatible trace metals (Zr, Nb, Mo, Hf, Ta, W) in the Indian Ocean. We will also reveal the distribution of platinum group elements (PGEs; Pd, Pt, Au) and the isotopic composition of molybdenum (Mo IC) and tungsten (W IC) at some stations.

**Sampling method (1) Trace metals:** Seawater samples were collected at all the CTD stations for bioactive trace metals and incompatible trace metals. Water samples were transferred from Niskin-X bottles to 500-mL polyethylene bottles (LDPE, Nalge) using a clean bell and acid-cleaned silicon tubing in a clean room constructed in the No.7 Lab. Some portions of the samples were filtered through a 0.2- $\mu$ m polycarbonate membrane filter (Nuclepore) by the pressure of nitrogen gas in a closed filtration system in a clean room (No.4 Lab). All the filtered and unfiltered samples for trace metals were acidified with 20% HCl (TamaPure AA-10, Tama chemicals) for bioactive trace metals and mixed acid of 1 M HF-5 M HCl (TamaPure AA-10 and AA-100) for incompatible trace metals. **(2) Mo IC, W IC and PGEs:** Water samples were passed through an AcroPak cartridge filter (Pall Life Sciences) by the pressure of compressed air and transferred from Niskin-X bottles to 250-mL LDPE bottles (Nalge) for Mo IC, 5-L cubic polyethylene bags for W IC, and 4-L LDPE bottles (Nalge) for PGEs at a few stations. The filtered samples were acidified with HCl (Toxic metal analytical reagent grade, Wako) for Mo IC and W IC, and HCl (Ultrapur 100, Kanto Chemicals) for PGEs.

**On land experiments** Samples will be purified by a column of chelating resins and the concentration of trace metals will be determined with ICP-MS. The isotopic composition of some metals will be measured by multi-collector ICP-MS.

## 8.2. Distribution of lead isotopic composition (Pb IC) in the Indian Ocean

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**Objective** Lead isotopes have been introduced to the oceans from various anthropogenic sources, such as industry and by combustion of leaded fuels for more than a century. These sources have a characteristic own range in the isotopic composition of Pb isotopes (Pb IC) and the changes in Pb IC through time are well recorded in coral. Therefore, variations in Pb IC in the oceans are easily characterized and will provide knowledge about contributions from various anthropogenic sources and pathways to the oceans. They will provide valuable constraints on a range of ocean processes and will also be useful for prediction of the response of the oceans to changes in environments.

No detail information about Pb IC is available in the Indian Ocean. In this study, we will reveal the sectional distribution of Pb IC in the Indian Ocean in detail.

**Sampling method** Seawater samples were collected at all the CTD stations. Water samples were filtered through an AcroPak cartridge filter (Pall Life Sciences) by the pressure of compressed air and transferred from Niskin-X bottles to 2-L rectangular polyethylene bottles (HDPE, Nalge) in a clean room constructed in the No.7 Lab. All the filtered samples were acidified with 20% HCl (Tamapure AA-100, Tama chemicals) in the No.4 Lab.

**On land experiments** Pb isotopes will be coprecipitated by magnesium hydroxide and isolated from seawater matrix by anion exchange column. The isotopic composition of Pb will be measured by multi-collector ICP-MS at Massachusetts Institute of Technology (MIT).

### 8.3. Fe(II) distribution in the Indian Ocean

Yoshiko Kondo, James W. Moffett

University of Southern California

Dissolved iron concentration in seawater is generally known as low because not only high biological demand but also thermodynamically favorable oxidation state, Fe(III), is strongly hydrolyzed at seawater pH and is relatively insoluble. However, in reducing environment, Fe concentrations are high because Fe(II) is highly soluble. Fe(II) is thermodynamically unstable in seawater, and it is rapidly oxidized by O<sub>2</sub> at seawater pH. Arabian Sea contains one of the ocean's three oxygen minimum zones, where oxygen levels low enough for denitrification to occur, but not fully anoxic to support sulfate reduction. Denitrification has a high Fe requirement associated with metalloenzymes for nitrate and nitrite reduction. Moffett et al. (2007) reported that the concentration of Fe(II) had a peak at the depth of nitrate maximum of the oxygen minimum layers in the Arabian Sea in the end of the south west monsoon/beginning of fall intermonsoon in 2004, suggesting that in situ redox cycling of Fe has important implications for the nitrogen cycle. In this cruise, we investigated the vertical profiles of Fe(II) from surface (10 m) to bottom layer during north east monsoon period in the Indian Ocean.

#### Materials and methods

##### 1) Distribution of Fe(II) in the Indian Ocean

Samples for Fe(II) analyses were obtained from 12L-Niskin bottles, mounted on the CTD rosette. These Niskin bottles were carried into bubble space inside the ship. Then filtered (pore size: 0.2  $\mu$ m) samples were transferred into 2 of 30-mL Teflon bottles inside the bubble; inside the one of two bottles, 480  $\mu$ L of 0.1  $\mu$ M MOPS buffer was already added to adjust the pH to  $\sim$ 7.2 to reduce oxidation rate of Fe(II) to Fe(III). No rinsing using sample seawater was performed for the Teflon bottles. A Waterville Analytical "FeLume" flow injection analysis (FIA) system with chemiluminescence detection method (King et al., 1995) was employed for Fe(II) measurements on board.

##### 2) Experiment at the Japanese GEOTRACES Intercalibration station

The oxidation rate of Fe(II) in the samples obtained by gravity, N<sub>2</sub> gas pressure and Air-compressor filtrations were compared to clarify the influence of sampling methods for Fe(II) analyses. 1 nM of Fe(II) were pre-added in the subsampling bottles. And then, the changes of Fe(II) concentrations in each samples were monitored for  $\sim$ 30 minutes from sampling.

#### Results

Vertical profiles of Fe(II) measured at natural pH and pH 7.2 at ER6 are shown in Fig. 1. The Fe(II) peak were observed around O<sub>2</sub> minimum zone.

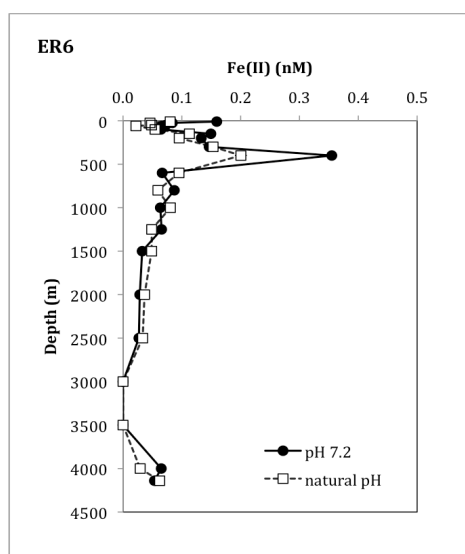


Fig.1 Vertical distribution of Fe(II) (<0.2  $\mu$ m) at station ER6.



Moffett J.W., Goepfert T.J., Naqvi S.W.A. (2007), Reduced iron associated with secondary nitrite maxima in the Arabian Sea. *Deep-Sea Res. I*, 54, 1341-1349.

King D.W., Lounsbury H.A., Millero F.J. (1995), Rates and mechanisms of Fe(II) oxidation at nanomolar total iron concentrations. *Environ. Sci. Technol.*, 29, 818-823.

## 8.4. Iron and copper speciation in the Indian Ocean

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### Purpose

Iron is an essential element required by all eukaryotes and its availability has been shown to control phytoplankton growth rate and primary productivity in high-nutrient low-chlorophyll regions as well as nitrogen fixation in subtropical/tropical oligotrophic waters. The dissolved iron is in extremely low concentrations in the open ocean and the vast majority is bound to strong organic ligands. Since organically bound iron is not directly available for algal uptake, it is necessary to measure the chemical speciation of iron in seawater for understanding iron nutrition status of phytoplankton in the ocean.

Like iron, copper is a redox-active transition metal, acts as a cofactor in several enzymes. Oceanic diatoms are known to use a copper protein for photosynthesis to reduce the need for iron. In addition, iron-limited marine diatoms possess a high-affinity iron transport system, which includes multi-copper containing ferroxidases as transmembrane ferric reductases, to access iron bound within strong organic complexes. Thus, investigations on the copper nutrition is also essential for a better understanding of how iron availability and speciation control primary productivity in the ocean.

In remote oceanic regions in the Indian Ocean, iron enters the ocean primarily through the atmosphere as dust, although seasonal upwelling of subsurface water may be another major source of iron in the Arabian Sea during the Southwest Monsoon. Atmospheric aerosol depositions also supply other trace metals to the surface ocean. Some aerosols have been shown to induce toxicity to picoeukaryotes and *Synechococcus* due to high copper concentrations in these aerosols, although some phytoplankton are known to release strong copper-complexing organic ligands in response to copper toxicity. Anthropogenic emissions are increasing atmospheric copper deposition, and this deposition may potentially alter patterns of marine primary production and community structure in high aerosol, low chlorophyll areas, such as the Bay of Bengal.

The present study was undertaken to provide data on iron and copper speciation in the Indian Ocean, and to understand phytoplankton growth responses to the availability of these elements.

### Methods

#### *Iron and copper speciation:*

Water samples were collected using acid-cleaned Teflon-coated 12-liter Niskin-X bottles on a CTD-Carousel system attached at the end of the titanium armored cable (8 mm o.d.) from the No.2 winch at station ER-2, 3, 5, 7, 8, 9 and 10 from 10, 100, 1000 m and near bottom as well as the layers of subsurface chlorophyll maximum and oxygen minimum. Additional samples were collected from 50, 200, 600, 2000 and 3000 m at station ER-10. After the recovery, Niskin-X bottles were placed in a clean-air booth and the sample seawater was filtered through an AcroPak 200 Capsule filter unit having 0.8/0.2  $\mu\text{m}$  pore-size Supor Membrane (Pall) attached directly to the spigot with silicon tubing under a pressure of 1 atm by compressed clean air. Filtered seawater collected in acid-cleaned 500-ml FLPE bottles were stored frozen under  $-20^{\circ}\text{C}$  for analysis of iron and copper complexing ligands in the onshore laboratory. Samples for analyses of dissolved iron and copper were collected in acid-cleaned 125-ml LDPE bottles and acidified to  $\text{pH} < 1.7$  with 20% quartz-distilled HCl (TAMAPURE AA-100).

#### *Atmospheric deposition of trace metals:*

Total (wet+dry) deposition samples were collected using a collector with a 30 cm i.d. acid-cleaned plastic funnel into acid-cleaned 250 ml LDPE bottles. The collector was set up at the front of the upper deck and the funnel was opened only under the against wind condition during the cruise. The sample bottle was checked at least once a day for exchange. Collected samples were frozen under  $-20^{\circ}\text{C}$  for onshore analysis of trace metals, anions and cations.

### ***Phytoplankton responses to atmospheric aerosol deposition:***

Potential effects of trace metals released from the deposited aerosols on phytoplankton growth were examined by onboard bottle incubation experiments using the surface water collected from 10 m depth by acid-cleaned Teflon-coated 12-liter Niskin-X bottles at stations ER-2 and 7. The surface water was homogenized in an acid-cleaned 20-liter polycarbonate carboys, filled with the sample water, and then the water was dispensed into 54, acid-cleaned, replicate 300-ml polycarbonate incubation bottles. Nine bottles were used for each treatment and the control. The treatments were additions of 0.6, 1.5 or 3% (v/v) total deposition samples collected near the experimental stations, and 1 nM FeSO<sub>4</sub> or CuSO<sub>4</sub> additions. Samples without addition were treated as controls. The bottles were incubated on deck in a running surface seawater bath to maintain surface seawater temperatures for 5 days. The incubation bath was covered with a neutral density screen, which shaded the ambient light to a 50% level. On day 1, 3 and 5 during the course of the incubations, three bottles were withdrawn for each treatment from the incubation bath at a time, and submitted to the measurements of nutrients, Chl *a*, and pico- and nano-phytoplankton abundance. Samples for plankton species composition were also collected on day 5. Replicate samples were taken from the replicate bottles. Samples at the starting point were collected directly from 20-liter carboy for determinations of these parameters as well as acid-dissolvable iron and copper concentrations.

The samples (100–200 ml) for Chl *a* measurement were filtered onto Whatman GF/F filter or 10 µm pore-size Nuclepore membrane filter by gentle vacuum filtration (< 200 mm Hg), and Chl *a* was extracted from the filters for 24 hr in N,N-dimethylformamide at –20°C. Extracted Chl *a* was determined onboard by the fluorometric technique with a Turner Designs 10-AU field fluorometer with the chlorophyll optical kit for the non-acidification method (Welschmeyer, 1994). Samples for nutrient analysis were collected in duplicate 10-ml acrylic tubes and stored at –20°C. Pico- and nano-phytoplankton samples (4.5 ml) for analysis by flow cytometry were preserved with EM grade glutaraldehyde solution (1% final concentration), frozen in liquid nitrogen, and then stored at –80°C. Plankton samples (150–250 ml) were preserved with lugol's solution and stored at 4°C for subsequent microscopic observation. For acid-dissolvable iron and copper analyses, unfiltered seawater samples collected in acid-cleaned 125-ml LDPE bottles were acidified to pH <1.7 with 20 % HCl (Tamapure-AA-100).

### **Future works**

#### ***Iron and copper speciation:***

Concentrations of natural organic ligands will be measured by competitive ligand exchange-cathodic stripping voltammetry using the 2-(2-Thioazolyazo)-*p*-cresol (TAC) as the competitive ligand for iron (Croot and Johansson, 2000) and salicylaldoxime (SA) for copper (Campos and van den Berg, 1994). The acidified water samples will be stored for more than three months, and then analysis of iron (III) concentration will be done by a chelating resin concentration and chemiluminescence detection method (Obata *et al.* 1993). Seawater samples will be UV-irradiated for 4 hr prior to the copper determination by cathodic stripping voltammetry (Campos and van den Berg, 1994). Speciation of Iron (III) and copper will be estimated from measured concentrations of total dissolved iron/copper and iron/copper binding organic ligands, and these conditional stability constants.

#### ***Atmospheric deposition of trace metals:***

Total (wet+dry) deposition sample will be filtered through a 0.4 µm pore-size Nuclepore membrane filter and the filtrate will be acidified with 4% HNO<sub>3</sub> (Tamapure AA-100) for analysis of Al, Ti, Mn, Fe, Co, Ni, Cu, Zn, Cd, Pb and Th using HR-ICP-MS (ELEMENT 2) by external standardization. Particles on the filter will be decomposed by microwave treatment with conc. HNO<sub>3</sub> and HF and samples diluted with Milli-Q water will be analyzed by HR-ICP-MS by internal and external standardization. Major anions and cations in the samples will be analyzed by an ion chromatography.

#### ***Phytoplankton responses to atmospheric aerosol deposition:***

Responses of surface plankton assemblage to the additions of total deposition samples as well as 1 nM iron and copper will be determined by changes in Chl *a* concentration, pico- and nano-phytoplankton abundance, plankton species composition, and consumption of macro-nutrients.

Flow cytometric analysis of pico- and nano-phytoplankton will be conducted for fixed samples using a PAS-III flow cytometer (Partec, Germany), equipped with a 488-nm Ar-ion laser whose power was

set to 20mW. Forward light scatter (FSC), side light scatter (SSC), green fluorescence (FL1, 520–550 nm), orange fluorescence (FL2, 570–610 nm, fluorescence mainly from phycoerythrin), and red fluorescence (FL3, >630 nm, fluorescence mainly from chlorophyll) will be measured on 4-decade logarithmic scales mapped on 256 channels and stored in list mode. FL3 is utilized as a trigger parameter to distinguish phytoplankton cells from heterotrophs and non-living particles. Based on FL2 vs. FL3 and FL3 vs. FSC cytograms, *Synechococcus* and *Prochlorococcus* can be distinguished from the other phytoplankton cells. After excluding *Synechococcus* and *Prochlorococcus* from cytograms, pico- and nano eukaryotes are identified. All the data will be analyzed using a software FloMaxs (Partec, Germany). Fixed water samples for microscopic observation of plankton species composition will be allowed to settle in glass sedimentation cylinders. The cells settled at the bottom of the sedimentation chambers will be observed using an inverted microscope. Nitrate+nitrite, nitrite, phosphate and silicate concentrations will be measured by the standard methods using a continuous flow analyzing system (BRAN+LUEBBE, AACSII).

## References

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## 8.5. Biogeochemical study of Fe(II) in the Indian Ocean

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### Introduction

Recently, the importance of iron on ocean primary production has been well known. Now the iron speciation is a main topics since the iron availability by phytoplankton depends on its speciation in seawater. Especially, Fe(II) is an important chemical species for iron acquisition by phytoplankton. However, the biogeochemical cycles of Fe(II) in the ocean are not well known yet. In this study. In addition, Fe(II) decrease soon in oxic circumstances, and increase slowly when there is organic matter. These problems have prompted us to devise in situ chemical analyzers GAMOS which can investigate *in-situ* spatial variation of Fe(II) . Now we determine dissolved Fe(II) in seawater of the Indian Ocean on board by luminol chemiluminescence method and GAMOS to compare the both results

### Methods

**Sampling:** Surface seawater samples were collected by X-Niskin samplers installed on the CTD-CMS system. Samples were immediately filtered with 0.2  $\mu\text{m}$  cartridge filter (Acropak, Pall). The samples for Fe(II) were introduced into the analytical system onboard.

**Analyses:**

On board analysis

On board the ship, the seawater samples were injected to the flow analytical system (King et al., 2000) after adjusting the pH of the samples at 6. (Hansard and Landing, 2009)

GAMOS

GAMOS (Geochemical Anomalies MONitering System) is an in situ flow-through chemical analyzer for the measurement of dissolved Fe(II) in sea water. GAMOS analyzes dissolved Fe(II) continuously using a luminal chemiluminescence method and flow injection analysis.

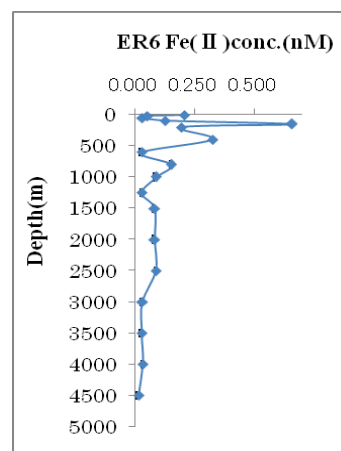
### Results

At the ER6 station, Fe(II) profiles display subsurface maxima which coincide with the oxygen minimum.

GAMOS data is now analyzed.

### References

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Hansard, S.P. and Landing, W.M. *Limnol. Oceanogr.*: *Methods* 7 (2009) 222.



## 8.6. N<sub>2</sub> fixation activity and diazotrophic diversity in the Indian Ocean

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### Purpose

It has long been thought that nitrate in deepwater is the major source of new production. However, recent studies have shown that biological N<sub>2</sub> fixation has a critical role in supporting new production in the oligotrophic tropical and subtropical waters. To elucidate spatial variation of N<sub>2</sub> fixation activity and diazotrophic diversity in the Indian Ocean, we conducted following experiments during this cruise of leg.1 and 2.

### Methods

Water samples for <sup>15</sup>N-<sup>13</sup>C assimilation experiments, chlorophyll *a*, nutrients, microscopic observation, suspended particulate matter (SPM), and DNA analysis were collected in an acid-cleaned bucket and Niskin-X bottles from those layers having surface light intensities of 100, 50, 25, 10, and 1%. The depth profiles of light intensity were determined using INF-300 (Biospherical Instruments) before the sampling.

Samples for <sup>15</sup>N-<sup>13</sup>C assimilation experiments were introduced into duplicate acid-cleaned 4.5 L polycarbonate (PC) bottles. <sup>13</sup>C-labeled sodium bicarbonate (99 atom% <sup>13</sup>C; Cambridge Isotope Lab.) was added to each bottle at a final tracer concentration of 200 μM before sealed with a thermoplastic elastomer cap. Then, using a gas-tight syringe, 2 ml of <sup>15</sup>N<sub>2</sub> gas (99.8 atom% <sup>15</sup>N; Shoko) was added into each bottle. The samples were incubated in an on-deck incubator, and the incubation was terminated after 24 hours by gentle vacuum filtration (<0.02 MPa) of the seawater samples through a precombusted GF/F filter. The filters were kept frozen (-20 °C) until on-shore analyses were performed.

Samples for chlorophyll *a* of 290 ml were filtered onto 25-mm Whatman GF/F filters, and the chlorophyll *a* concentrations were measured fluorometrically using a Turner Design 10-AU fluorometer after extraction with N, N-dimethylformamide on board.

Samples for nutrients analysis were collected in acid-cleaned 50 and 100 ml polypropylene (PP) bottles. Concentrations of nitrate+nitrite and soluble reactive phosphorus were immediately determined using a high sensitive colorimetric system (Hashihama et al., 2009, GRL 36, L03610).

Samples for microscopic observation were collected in 500 ml PP bottles and were

preserved with acidified Lugol's solution. The samples were kept in darkness, and microplanktonic diazotrophs, *Trichodesmium* spp. and *Richelia intracellularis*, will be enumerated by using an inverted microscope on land.

Samples for SPM were collected in 2L PC bottles from the surface using a polyethylene bucket, and were subsequently transfer into a PP tank. SPM was separated by vacuum filtration from the seawater through a 25 mm diameter, 0.4  $\mu\text{m}$  pore-size Nuclepore<sup>®</sup> filter, and then was stored in a refrigerator for ashore analysis.

Samples for DNA analysis were collected in 2L PC bottles, and were gently filtered (<0.01 MPa) onto in-line 47 mm diameter, 0.2  $\mu\text{m}$  pore-size Nuclepore filters. The filters placed in 2 ml centrifuge tube containing 500  $\mu\text{l}$  of Tris-EDTA (TE), and were stored in liquid nitrogen for ashore analysis.

## 8.7. Iodine isotopic ratio ( $^{129}\text{I}/^{127}\text{I}$ ) in the Indian Ocean

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### Background and objectives:

Long lived radio isotope  $^{129}\text{I}$  (half life =  $1.57 \times 10^7$  yr) is naturally produced cosmogenically and fissiogenically, i.e., by the interaction between cosmic rays and Xe in the atmosphere and by the spontaneous fission of  $^{238}\text{U}$  in the crust. However since late 1950's, by the nuclear weapons testing and following waste nuclear fuel reprocessing, enormous amount of  $^{129}\text{I}$  has been released into earth surface environment so that nowadays the  $^{129}\text{I}/^{127}\text{I}$  ratio had been several orders higher than before 1950's.

As  $^{129}\text{I}$  is radio isotope, some attempts to use this isotope system as a dating tool for the time scale of Myr orders have been tried. Several conditions are required for proper dating using a radioisotope-stable isotope system. Most important is that the initial ratio is constant enough everywhere and every time concerned. In the case of iodine isotope system, residence time in the ocean (to be estimated as about 300 kyr) is much longer than ocean circulation period (1-2 kyr) and much shorter than its half life. Since the exchange time between atmosphere and ocean should be much shorter, atmosphere-ocean system can be regarded as fully open system with respect to the iodine isotope system. Next important issue is to know the initial value. As mentioned above, anthropogenic  $^{129}\text{I}$  was severely injected into the earth surface environment, so we cannot now the natural initial  $^{129}\text{I}/^{127}\text{I}$  ratio by measuring environmental sample today. One way to dare this situation is to obtain samples collected before 1950 and preserved well. Another way is to investigate far from surface environment, i.e. deep under the ground or deep in the ocean.

J. Moran et al. (1998) proposed  $1.5 \times 10^{-12}$  as the initial ratio by measuring depth profiles of marine sediments off coasts around the north and south America. Recently U. Fehn et al. (2007) also presented iodine isotope data of old sea weeds and supported that initial value. Using this initial value, U. Fehn and his colleague measured several brines or pore water found near the methane hydrates or natural gases and determined their "iodine age". Their results often show large discrepancy between "iodine age" and the age of sediments from which brine or pore water was sampled. Typical example is the case of



Mobara, Chiba prefecture, Japan performed by Y. Muramatsu et al. (2001). In Mobara region iodine-rich brine is existent with natural gas in the Kazusa formation which sedimentary age is 1-3 Ma. However average  $^{129}\text{I}/^{127}\text{I}$  ratio in the brine is  $1.7 \times 10^{-13}$  which corresponds to about 50 Ma. Situations in the other sites (Blake ridge, Peru margin, Off the coast of New Zealand, etc) are more or less the same, i.e., the “iodine age” is much older than “sedimentary or geologic age”. While these results suggest somewhat complicate history of the generation and migration of methane hydrates or natural gas and iodine, on the other hand, we have question whether the initial value proposed by J. Moran et al. is really true or not.

Actually, some layers in the depth profiles in the Moran’s paper show obviously lower  $^{129}\text{I}/^{127}\text{I}$  ratio which is interpreted as the mixing with older iodine. Also in the Fehn’s paper some sea weeds show significantly lower  $^{129}\text{I}/^{127}\text{I}$  which is interpreted as a local effect.

Here one of motivations of my participation with this research cruise is to measure  $^{129}\text{I}/^{127}\text{I}$  ratio in deep sea water far from continents. It is about a thousand year for a surface water column come to deep sea, so dissolved component of anthropogenic  $^{129}\text{I}$  could not yet reach deep sea. Although micro vials would carry modern iodine more quickly from surface to deep sea, they should directly cumulate on to sea floor and it would take much more time to release their iodine back into sea water than several decades. Thus  $^{129}\text{I}/^{127}\text{I}$  ratio in dissolved iodine component in deep sea should reflect the initial value.

My objectives are:

- 1) To see what an extent anthropogenic  $^{129}\text{I}$  is intrude from depth profile from surface to bottom and
- 2) To re-examine the natural initial value of  $^{129}\text{I}/^{127}\text{I}$  in marine environment as well as its global homogeneity.

## Method and sampling strategy:

To determine  $^{129}\text{I}/^{127}\text{I}$  ratio in sea water, there are two methods to treat a sample, using carrier or not. If you have  $^{129}\text{I}$  free iodine reagent and target isotopic ratio is high enough compared with the background of Accelerator Mass Spectrometry, it is convenient to use carrier. Though the least isotopic ratio of iodine carrier ever known is  $2 \times 10^{-14}$ , it can be used as a carrier if our target range of isotopic ratio for deep sea is on the order of  $10^{-13}$ . For this method, 1L or 3L sea water sample, for each observation point and depth, was collected.

In the case of carrier method, error involved in the final result should be greater as the target ratio is lower. We also try carrier-free method. In this method, 20L sea water is needed for 1mg iodine required by AMS, because the iodine concentration in sea water is

typically 55ppb. From 20L sea water AgI-AgCl co-precipitation was collected by addition of AgNO<sub>3</sub>. Pure AgI extraction from the co-precipitation will be the task after taking back to the laboratory. If this purification is successful, we can determine isotopic ratio of sea water as low as 10<sup>-14</sup> order.

Sea water sampling was held at the observation points ER-5, 6, 7, 8, 9, 10. Most samples for carrier method were collected from CTD-bubble category with 0.2μm filter to avoid micro vials. Basically sampling was done for every depth layer to see depth profile. A part of samples was also collected from LV category with 0.5μm filter. At ER-9, non filtered samples were also collected for comparison. All samples for carrier method was contained in 1L bottle. 3mL Na<sub>2</sub>SO<sub>3</sub> was added to each bottle to stabilize the chemical form of iodine (to I<sup>-</sup>) and sealed.

For carrier-free method, samples were collected partially from CTD-bubble category and mainly from LV category.

Separately, 50mL sea water sample was collected from CTD-bubble category on every point and every layer. These samples will be freezed to fix the chemical form of iodine. After the cruise iodine concentration and, if possible, chemical form (iodide or iodate) will be analyzed.

Also some of multiple core samples from sea-floor were obtained to see the continuity of iodine isotopic ratio and to observe the bioturbation zone.

<sup>129</sup>I/<sup>127</sup>I ratio will be measured by Accelerator Mass Spectrometry and iodine concentration by ICP-MS. All analysis will be held in next year, after the end of KH09-5 cruise.

#### *Acknowledgement:*

I am grateful to Prof. T. Gamo, Prof. H. Obata, Dr. N. Nakayama and all other project staffs of this research cruise for allowing me to join this cruise. I thank Prof. H. Nagai, Dr. H. Tazoe and T. Yamagata for cooperation for carrier-free method. I also appreciate Prof. M. Murayama for his suggestion and future collaboration to analyze multiple core samples. Finally I deeply thank all of CTD-bubble operators to collect clean sea water samples.

## 8.8. Molecular hydrogen observation in ocean surface using the underway water samples

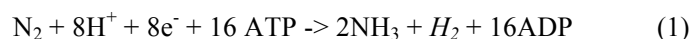
Shinsuke Kawagucci (Precambrian Ecosystem Laboratory, JAMSTEC)

Toshitaka Gamo (Ocean Research Institute, the Univ. of Tokyo)

### Purpose

Molecular hydrogen, H<sub>2</sub>, is a trace component of oxidized modern earth. H<sub>2</sub> dissolved in oxic oceanic water is generally undersaturated against the air-sea equilibrium due to rapid aerobic microbial consumption occurring through day and night, whereas H<sub>2</sub> supersaturation has been observed in surface and at around Chlorophyll maximum depth in oligotrophic ocean.

Biological nitrogen fixation is now recognized as one of the most probable H<sub>2</sub> production processes in low-latitude surface seawater. Marine biological nitrogen fixation is a key metabolism to supply new N-nutrient at oligotrophic low-latitude surface by reducing biologically quasi-inert nitrogen gas to ammonia accompanied with H<sub>2</sub> production as a following:



Newly fixed nitrogen is an important factor to control marine primary productivity, but the temporal, spatial, and magnitude variations of nitrogen fixation activity remain inadequately determined. It is largely due to a lack of quick, direct, and easy technique to detect the activity and determine how amount N has been fixed. Recently, Moore et al. (2009) revealed a significant relationship between H<sub>2</sub> concentration and nitrogen fixation rate in low-latitude surface water, and proposed that a monitoring of surface H<sub>2</sub> concentration could be used quickly to figure out the spatial extent of active marine nitrogen fixation. In this cruise, we determined H<sub>2</sub> concentration continuously in water pumped up from a bottom of R/V Hakuho-maru (ca. 5 m depth) in order to describe a distribution of nitrogen fixation activity in Indian Ocean.

### Method

Seawater from the 5<sup>th</sup> Lab. tap was directed to the bottom of a 120 mL brown-colored glass vial with no air bubbles through a PTFE tube. In some cases, seawater from the tap was first introduced to a 12 L glass tank and then subsampled from the tank to the vial. The vial was allowed to overflow by 2 volumes before the tube was slowly withdrawn. After the addition of 0.5 mL HgCl<sub>2</sub>-saturated solution for poisoning, the PTFE-lined butyl-gum septum was used to cap the vials. For comparison, seawater samples were also taken by bucket (0 m) and X-type Niskin samplers mounted on the CTD-CMS system frame (10 – 100 m depths).

Molecular hydrogen was analyzed at an onboard laboratory within 6 hours after subsampling to avoid sample alteration during sample storing. To make head space in the vial, 30 mL of sample water was substituted by 30 mL of H<sub>2</sub>-free air using a gas-tight syringe; then the vial was put on an automatic shaker and shaken upside down for 6 minutes to achieve a complete equilibrium between the dissolved and head space gases in the vial. The equilibrated headspace was taken by another gas-tight syringe and then injected into a gas chromatograph equipped with a trace reduced gas detector (TRD-1: Round Science Inc., Japan) which is based on the principle of mercuric oxide reduction. Hydrogen was separated from the other components at 70 °C on a 3 m column packed with Silicagel and subsequently at 70 °C on a 3 m column packed with Molecular sieve 5A giving retention times of 6 min..

## **Results**

H<sub>2</sub> concentrations of all the underway samples (running and stationary) were more than 10 nmol/L. On the other hand, the bucket and Niskin samples showed H<sub>2</sub> concentrations less than 1 nmol/L, within the range of oceanic H<sub>2</sub> concentration observed so far. These facts suggest unfortunate H<sub>2</sub> production at the pumping system of the Hakuho-maru. At this time, we cannot know the H<sub>2</sub> production process at the pumping system. Dataset from the bucket and Niskin observations will be analyzed.

8.9. Isotopic composition of suspended particulate nitrogen ( $\delta^{15}\text{N}_{\text{sus}}$ ) and organic carbon ( $\delta^{13}\text{C}_{\text{sus}}$ ) in the surface waters of the western Indian Ocean

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Objectives: 1) To determine the large scale distribution of nitrogen and carbon isotopic composition of suspended particles in the surface waters of the western Indian Ocean  
2) To understand the factors contributing to the variability in isotopic composition of particulate nitrogen and particulate organic carbon, taking into account a wide range of hydrographic settings and types of planktonic communities  
3) To examine the relationship between primary productivity and isotopic composition of particulate nitrogen with a view to the potential for the application of  $\delta^{15}\text{N}$  signatures as past and present oceanographic tool.  
4) To understand the fate of suspended organic carbon to depth – mainly to estimate how many trophic levels it pass through before it leaves the thermocline.  
5) To examine the factors controlling photosynthetic  $^{13}\text{C}$  fractionation ( $\epsilon_p$ ) and identify the mechanisms of inorganic carbon acquisition in natural phytoplankton assemblages.

Methods: About 15 to 20L of samples were filtered through pre-combusted, at  $400^\circ\text{C}$  for 6 hours, GF/F filter paper at  $<0.5$  bar vacuum, immediately after the sampling and stored at  $-80^\circ\text{C}$ . The filter papers will be vacuum dried and inorganic carbon is removed by exposing the filter papers to the hydrochloric acid fumes for over night. The filter papers are combusted at  $1000^\circ\text{C}$  in the elemental analyzer coupled to Isotope Ratio Mass Spectrometer (IRMS; Delta V Plus, Thermo Fisher, Germany) for determination of concentrations and isotopic ratios of particulate organic carbon and particulate nitrogen.

Samples: 15-20L of surface sample were collected at 2 deg interval from  $17^\circ\text{N}$  to  $3^\circ\text{S}$  and  $5^\circ\text{S}$ ,  $10^\circ\text{S}$ ,  $15^\circ\text{S}$  and  $20^\circ\text{S}$  using underway clean surface sample supply tap. In addition to this, samples were also collected from surface, 50 and 100m at all stations from  $17^\circ\text{N}$  to  $20^\circ\text{S}$ .

## 8.10. Redox sensitive elements Re, Os and U in Arabian Sea

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**Purpose:** Arabian Sea is one of the most productive zones of the world due to intense upwelling owing to monsoon winds and high dust flux from the nearby landmass. High primary productivity causes oxygen minimum zone (OMZ) in the intermediate waters of the Arabian Sea. The OMZ and process of denitrification in the Arabian Sea is expected to have sufficient control on the internal cycling and distribution of the various trace elements and isotopes (TEIs) particularly of those sensitive to redox condition, such as U, Mo, Re and Os. An effort is being made to assess the impact of the OMZ on the distribution of TEIs in the Arabian Sea.

**Methods:** Samples were collected from 12l Niskin sampler on a clean CTD rosette and were filtered through 0.2 mm filters (acropak) in a clean lab right after their collection. The samples will be analysed for Os (isotopic composition  $^{187}\text{Os}/^{188}\text{Os}$  and concentration), Re and U concentrations after sample extraction and preparation in the clean lab at PRL. The determinations will be made on Thermal Ionization Mass Spectrometer (for Os) and Inductively Coupled Plasma-Mass Spectrometer (Fro Re and U) after their extraction from seawater samples<sup>[1], [2]</sup>.

**Samples:** 1l of seawater samples collected at stations ER5 to ER10.

### References:

- [1] Levasseur et al, *Science* **282**, 272 (1998) doi: 10.1126/science.282.5387.272
- [2] Colodner et al. *EPSL* **131**, (1995) 1-15

## 8.11. Oxygen isotope ratio ( $^{18}\text{O}/^{16}\text{O}$ ) in the Southern Ocean

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High-latitude Southern Ocean is experiencing a rapid salinity change. Shelf and Bottom Water freshening have been reported for some regions and this may lead to a change in global meridional overturning circulation. Increased land ice melting, increased precipitation, and decreased sea ice production can be one of the causes of these freshenings but their reasons are still largely unknown.

Stable isotope of oxygen is a useful indicator in estimating freshwater contribution to the watermasses in the Southern Ocean. Sustained measurements of oxygen isotope, together with salinity, can lead to a better understanding of the cause of those salinity changes. In this cruise water samples are taken to establish a baseline for comparison with future oxygen isotope measurements in this region.

Sampling was performed at station 62S, 40E in the Indian Ocean sector of the Southern Ocean. Samples are collected by 30 mL glass vials with plastic caps and polypropylene inserts. Vials are sealed with Parafilms and stored in a refrigerator just before the analysis. Measurements are to be done by Finnigan DELTA plus at Institute of Low Temperature Science, Hokkaido University, by the standard equilibration of the samples with  $\text{CO}_2$  at 18 °C. The measurements were made relative to an internal laboratory standards 18N and UP4, which were calibrated against VSMOW2 and SLAP2 supplied by IAEA. All samples are prepared with 5 ml and analyzed in duplicate with the mean precision of the duplicates being 0.02 ‰.

## **8.12. Chemical composition of suspended particles in the Indian Ocean and Antarctic Sea**

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### **Purpose**

In the ocean, various kinds of particles exist, for example, mineral particles transported from the atmosphere and rivers, anthropogenic particles and particles produced in seawater through biological activities and chemical reactions. Thus the differences of chemical compositions and size of suspended particles in seawater depend on their origins. By studying the chemical composition of suspended particles in seawater, we might understand the origin and the feature of water masses. Also, suspended particles are thought to play important roles in oceanic biogeochemical cycles.

During this cruise, we will study the chemical compositions of suspended particles in the Indian Ocean and Antarctic Sea, and clarify the feature and behavior of particles in this oceanic region.

### **Sampling**

Surface waters were collected by using a polyethylene bucket. Vertical samples were obtained using the CTD-CMS at most sampling stations (ER02, ER03, ER05, ER06, ER07, ER09, ER10, ER11, ER12 and ER14).

### **Methods (Filtration)**

Seawater samples (100-10000ml) were filtered through 25mm, 0.4  $\mu\text{m}$  porosity Nuclepore filters for microscopic analyses and 47mm, 0.2  $\mu\text{m}$  porosity Supor filters for trace-metal analyses immediately after sampling. The filters were rinsed with 200ml of Milli-Q water.

### **Analysis**

Particles collected on the filters were preserved at 4 °C in a refrigerator. The shape and size of particles will be observed with the Scanning Electron Microscope (SEM) and the chemical composition of particles will be analyzed with Energy Dispersive Spectroscopy (EDS) or Electron Probe X-ray Micro Analyzer (EPMA) in the laboratory.



### 8.13. Distributions of nutrients and associated phytoplankton dynamics in the surface water of subtropical and tropical India Ocean

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Concentrations of nitrogenous and phosphorus inorganic nutrients at the surface of the tropical and subtropical oligotrophic region are generally below the detection limits of conventional analytical methods. Recent studies on nutrients using highly sensitive analytical methods have shown that concentrations of nutrients vary considerably at nanomolar levels and the variation poses significant impacts on plankton dynamics (Karl, 2007). This is well exemplified by a tight coupling between nutrient concentrations and dinitrogen fixation in the subtropical western North Pacific (Hashihama *et al.*, 2009; Shiozaki *et al.*, 2009). However, little is known on distribution of nutrients and associated phytoplankton dynamics in the Indian Ocean and its adjacent waters. We examined these issues during the present cruise.

Seawater was continuously pumped up from the bottom of the ship during cruising, and introduced to an analyzing system (Hashihama *et al.*, 2009). Concentrations of nitrate+nitrite (N+N), soluble reactive phosphorus (SRP), and ammonium were determined using a highly sensitive colorimetric method whose detection limit was 3 nM of these nutrients. Temperature and salinity were recorded continuously by an Ocean Seven 301 (Idronaut), and chlorophyll fluorescence by an *in vivo* fluorometer (Chelsea). These sensors were calibrated against discretely collected subsamples. Samples for phytoplankton were discretely collected, and were fixed with 1% glutaraldehyde and frozen immediately in liquid nitrogen for flowcytometry, or fixed with 0.6% Lugol solution for microscopy on land. Particles for HPLC pigments were filtered on GF/F filters and stored at -80°C. Subsamples for molecular biology were gently filtered (<0.01 MPa) onto in-line 0.2 µm Nuclepore filters. The filters were placed in 2 ml centrifuge tube containing 500 µl of Tris-EDTA (TE), and stored in liquid nitrogen for ashore analysis.

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#### 8.14. Intercalibration during GEOTRACES Indian Ocean Cruise and establishment of GEOTRACES baseline station in the Indian Ocean

Hajime Obata<sup>1</sup>, Kazuhiro Norisuye<sup>2</sup>, Jun Nishioka<sup>3</sup>, Shigenobu Takeda<sup>4</sup>, Hirofumi Tazoe<sup>5</sup>, Tae Jin Kim<sup>1</sup> and Toshitaka Gamo<sup>1</sup>

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4. Faculty of Fisheries, Nagasaki University
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##### 1) Introduction

“The process, procedures, and activities used to ensure that the several laboratories engaged in a monitoring program can produce compatible data. When compatible data outputs are achieved and this situation is maintained, the laboratories can be said to be “intercalibrated” (Taylor, 1987).” Intercalibration activity is an important part in the international GEOTRACES program. During the GEOTRACES Indian Ocean, we have performed some exercises to ensure our clean sampling system. We have also collected some intercalibration samples to distribute to international community. By compiling the data collected here, we will establish a GEOTRACES baseline station in the Indian Ocean.

##### 2) Methods

Intercalibration was carried out at ER-10 (20 °S, 73°E) in the western part of the central Indian Ocean Basin.

##### 2-1) Comparison of sampling methods

Seawater samples for contamination-prone key parameters were collected with Teflon-coated X-type Niskin samplers, which were precleaned with 1% of detergent (Extran MA01, Merk), 0.1M hydrochloric acid and MQ water successively. Samples were collected at 20 m, 100 m, 200 m, 400 m, 600 m and 1000 m with the samplers attached to Kevlar wire. We also collected seawater samples at the same depths with 24 bottles of X-type Niskin samplers attached to CTD-CMS system. The CTD-CMS system was connected to titanium-armored cable.

We carried the Niskin samplers to a clean area, “bubble” in the laboratory, which was packed with polyethylene sheets. Inside the “bubble”, clean air, passing HEPA filters, was flown. All the seawater samples were filtered with a same 0.2 µm capsule filter (Acropak, Pall) with compressed air after 30 second flushing. As a contamination-prone key parameter, iron in seawater was determined onboard the ship with chelating resin preconcentration and chemiluminescence methods (Obata et al., 1993; 1997). Other contamination-prone key parameters, such as Zn, Al and Pb, will be determined at land-based laboratories.

Seawater samples for radiogenic key parameters, like <sup>230</sup>Th, <sup>231</sup>Pa and Nd isotopes, were collected with X-type Niskin samplers mounted to CTD-CMS system mentioned above. The seawater samples were also collected with a large-volume water sampler (Nichiyu Giken). The samples collected with LV samplers were filtered with 0.5 µm-pore size wind-cartridge filter (Advantec) for Nd isotopes.

##### 2-2) Comparison of filtering method.

To compare filtering methods, seawater samples were collected for determination of contamination-prone key parameters. For this examination, seawater samples collected at depths of 20m and 1000m were used. Seawater samples were filtered with two kinds of capsule filters, 0.2 µm-pore size Acropak (Pall) and 0.22 µm-pore size Milli-pak (Millipore). Seawater was passed through the filters with compressed air or only with gravity in the Bubble. Unfiltered samples were also collected in the Bubble and filtered with 0.2 µm Nucleopore filters pressured with nitrogen gas in a built-in clean laboratory. The contamination-prone key parameters will be determined in these samples, such as Fe, Zn, Al and Pb.

##### 2-3) Intercalibration samples for international community

For the purpose of international intercalibration on contamination-prone key parameters in seawater, we collected 20L of filtered seawater at depths of 50m, 600m, 1000m and 2000m.

The seawater was filtered with 0.2 µm-pore size Acropak (Pall) and stored in low-density polyethylene bottles. The seawater was acidified with 80 mL of ultrapure 6M hydrochloric acid (Tampure AA-100). After checking the quality and stability of the sample, we hope to distribute sub-samples to international GEOTRACES community.

#### 2-4) Establishment of a baseline station in the Indian Ocean.

To establish a GEOTRACES baseline station, we have collected seawater samples for vertical profiles of key parameters. The samples will be analyzed mainly by Japanese Geotracers. We also collected sub-samples for determination of key parameters by the international community. Samples were collected at the depths of 50m, 200m, 600m, 1000m, 2000m, and 4000m. We prepared 4 sets of these vertical-profile samples for contamination-prone key parameters, 2 sets for Nd isotopes, 2 sets for  $^{230}\text{Th}$  and  $^{231}\text{Pa}$ , and 1 set for Pb isotopes. By compiling the data sets of key parameters, we will establish the first GEOTRACES baseline station in the Indian Ocean.

## 8.15. Distribution of Total Inorganic Chromium in Indian Ocean

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Thermodynamic calculations predict that the predominant oxidation state of chromium should be chromium(VI) in oxygenated seawater at the natural pH(ca. 8.0). According to the results obtained by many researches, however, a few percentage of dissolved inorganic chromium exists in chromium(III), while the predominant species in the oceans are chromium(VI) .

The previous observations in some stations in the oceans have revealed that the typical vertical profile of both chromium(VI) and total inorganic chromium, the sum of chromium(III) and chromium(VI), is almost uniform through the water column, and slightly decreased and fluctuated in the euphotic zones. Nevertheless, the global oceanic distribution of chromium is not yet clear. In the recent observation in the central and northern Pacific Ocean, it was found that the distribution patterns of total inorganic chromium indicates the remarkable difference between the central area and the northern area [1].

The purpose of this research is to obtain the regional distribution of total inorganic chromium in Indian Ocean in order to clarify the geochemical significance of chromium in the ocean by discussing the oceanic process affecting the distribution of chromium species.

### Sampling and treatment

Seawater samples were collected by Teflon-coated X-Niskin samplers installed on the CTD-CMS system. All samples were filtered through an in-line filter attached to each Niskin sampler and acidified at pH 1.3 by adding hydrochloric acid (Tamapure AA-100 grade).

### Analysis

Total inorganic chromium in the samples will be collected by the solid phase extraction as the complex with 8-quinolinol after the reduction of chromium(VI) to chromium(III), and then determined by graphite furnace atomic absorption spectrometry [2].

### Reference

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## 8.16. Dissolved and colloidal iron distribution in the Indian Ocean: Onboard measurement for vertical section observation in the GEOTRACES program

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Trace elements serve important roles as regulators of ocean processes, including marine ecosystem dynamics and carbon cycling. Especially, iron plays important roles in the ocean as nutrients, therefore, biogeochemical cycling of iron has direct implication for research. To determine iron distribution in the Indian ocean, including its concentration and chemical/physical form, and to evaluate the sources, sinks, and internal cycling of these species to characterize more completely the physical, chemical and biological processes regulating their distributions, we conducted longitudinal vertical section observation and onboard measurement of dissolved iron.

Most research studying iron dynamics in seawater examines traditional categories of particulates and dissolved iron. Operationally, these categories are defined by simple membrane filtration with 0.2 or 0.45  $\mu\text{m}$  pore size filters. The traditional dissolved fraction, however, include substantial amount of small colloidal particles (Nishioka et al., 2001). Moreover, previous study suggested that iron in the small colloidal particle fraction was the most dynamic size fraction in the ocean ecosystem and biogeochemical processes (Nishioka et al., 2001; Bergquist et al, 2007). Thus, more information on iron speciation, including colloidal iron, is required to better understand the biogeochemical dynamics of iron in seawater. In this study, trace metal clean ultra-filtration using hollow fiber filter (0.03  $\mu\text{m}$ ) were conducted for determine the concentration of soluble and colloidal fraction of iron from seawater, and spatial distributions of the size-fractionated iron concentrations in the Indian Ocean were examined.

All samples were measured onboard with standardizing by SAFe international standard seawater (S and D2).

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### ***8.17. Determination of acid dissolved and dissolved metals in the Indian Ocean -The source of bioactive trace metals-***

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**Purpose:** Generally, dissolved bioactive trace metals are released from the dissolution of particulate matter in the ocean. Some trace metals, such as Al, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb, might be necessary for the phytoplankton growth in the ocean. Therefore, the bioactive trace metals might be released from the biological particles such as phytoplankton. However, there are a lot of particle with various source in the ocean.

In this study, we research the distribution of bioactive trace metals both dissolved and particle (acid dissolved fraction) by ICP-MS and the individual particle analysis of particulate matter by SEM-EDX for the elucidation of source of bioactive trace metals in the ocean.

**Sampling:** Seawater samples were collected by acid-cleaned Teflon-coated 12L Niskin Bottle. After collection, one of seawater samples for “unfiltered sample” were transferred directly to acid-cleaned Nalgene bottles, and another seawater samples for “dissolved sample” were filtered with Acropak (0.2  $\mu\text{m}$ ) and then transferred to acid-cleaned Nalgene bottles. After dispensation, all samples were acidified to pH 1.8 by adding ultra-pure hydrochloric acid solution (TAMAPURE AA-100, Tamakagaku co ltd). All dispensation and filtration process were carried out in the “bubble” clean room on shipboard. The seawater samples were filtered by Nucleopore filter (0.45 $\mu\text{m}$ ). The filter was rinsed with 250 ml of Milli-Q water for desalination. The particulate samples on the filter in the plastic case were stored in the refrigerator until analysis.

**Method:** Unfiltered samples will be stored in the laboratory for three month and then filtered with Acropak (0.2  $\mu\text{m}$ ) in the clean room. The determination of bioactive trace metals in both filtered and unfiltered seawater sample was carried out by the chelating resin solid phase extraction ICP-MS method. The individual particulate analysis of particulate sample was carried out by SEM-EDX.

## **The Cruise Report for Ocean Carbon Group (Xiamen University, China) Joining the GEOTRACES Japanese Cruise (Leg-1 of KH-09-5 Onboard R/V HAKUHO-MARU) in the Indian Ocean in November, 2009**

### ● Objectives

The primary purpose for participants from Xiamen University (XMU) is to get experienced on international research vessels. Under the condition that sampling is possible, the participants from XMU would like to take CTD cast samples as the routine parameters and underway pumping samples for comparing with the CTD cast samples.

### ● Study Area



**Fig.1 Study Area and Cruise Trajectory (Red Line)**

### ● Participants

Name	Gender	E-Mail	Principalship
Nan Zheng	Female	zhengnan@xmu.edu.cn	Research Assistant
Qian Li	Male	lipb@xmu.edu.cn	Ph.D. Candidate

**Ocean Carbon Group  
Xiamen University, China**

- Results

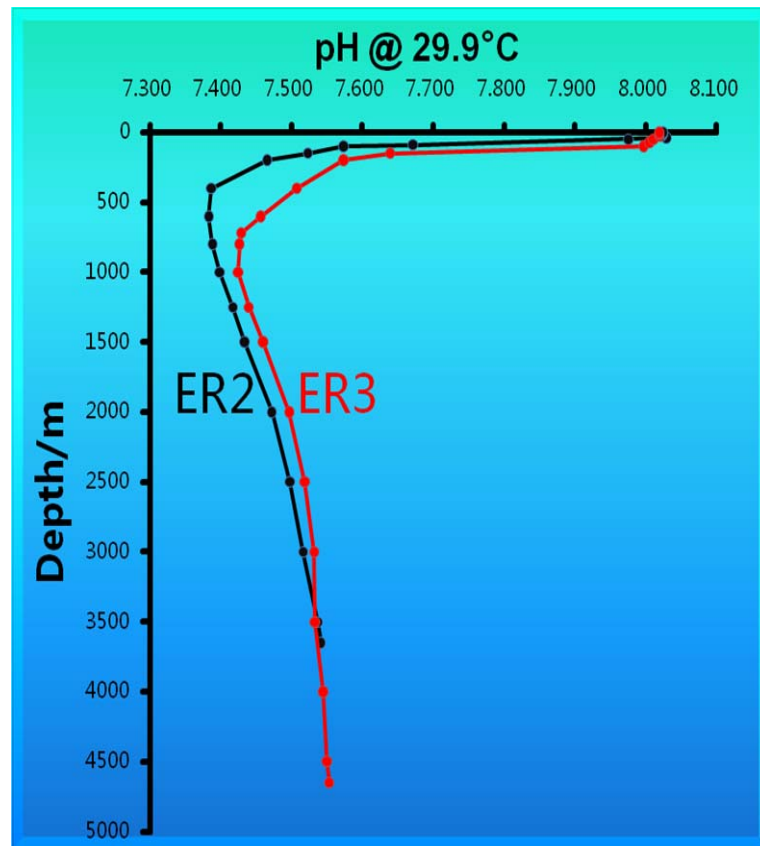


Fig. 2 Comparison of depth profiles of pH (the black line indicates the profile from ER2 Station & the red line indicates the profile from ER3 Station)

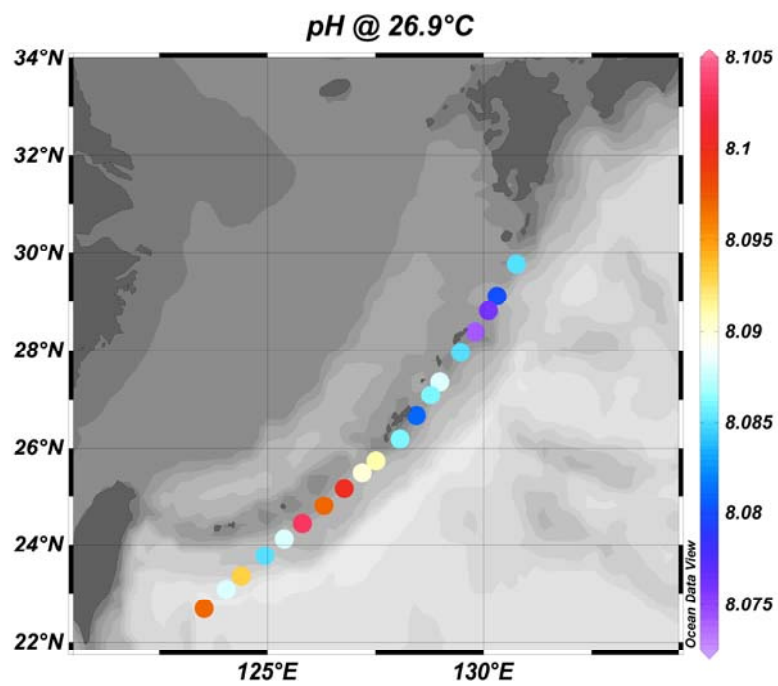


Fig. 3 the distribution of pH along Okinawa



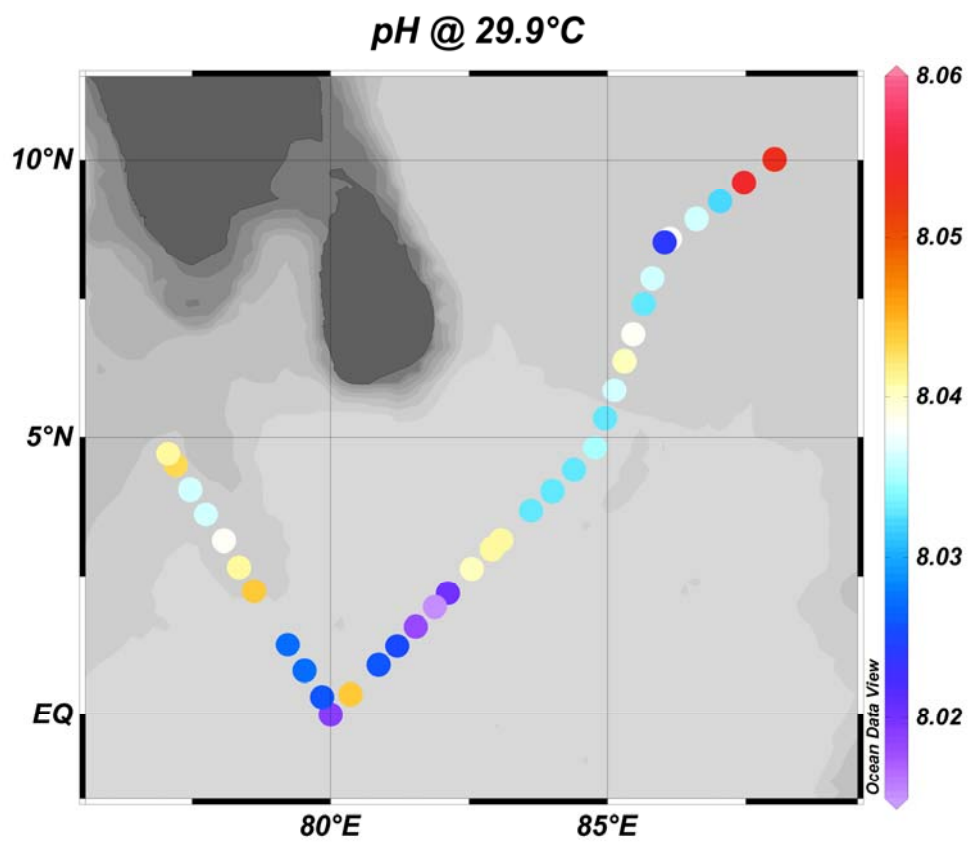


Fig. 4 the distribution of pH in Indian Ocean

Tab. 2 Parameters to be sampled and measured

No.	Type of Sampling	Parameter	Methods	Instruments	Number of Samples	Remarks
1.	CTD Cast Sampling (ER1-Test, ER2 & ER3) &	pH	Potentiometric pH Measurement Based on Total Scale Buffer	Thermo pH Meter		Measuring on board
2.	Underway Pumping	Total Alkalinity	Potentiometric Titrimetry	Automatic Titrator		Taking home
3.	Sampling (in the Japanese EEZ & open ocean in Indian Ocean)	DIC	Infrared Spectrophotometry	Model AS-C3 DIC Analyzer		
4.	CTD Cast Sampling (ER2 & ER3)	DOC	High Temperature Catalytic Oxidation	SHIMADZU TOC-V <sub>CPH</sub>	40	
5.		Ca	Potentiometric Titrimetry	Automatic Titrator	40	
6.		Ca isotopes	MC-ICP-MS	MC-ICP-MS		

## 8.19. Biogeochemical study of Fe(II) in the Indian Ocean using an in-situ analyzer

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### Introduction

Recently, the importance of iron on ocean primary production has been well known. Now the iron speciation is a main subject since the iron availability by phytoplankton depends on its speciation in seawater. Especially, Fe(II) is an important chemical species for iron acquisition by phytoplankton. However, the biogeochemical cycles of Fe(II) in the ocean are not well known yet because Fe(II) is easily oxidized in an oxic condition after sampling, which makes it difficult for us to determine Fe(II) in seawater. To solve these problems, we have developed a new method to determine Fe(II) in seawater using an in-situ chemical analyzer (GAMOS). During this cruise, we have investigated spatial variations of Fe(II) in the Indian Ocean using the in-situ analyzer. We have also determined dissolved Fe(II) in seawater on board the ship by conventional luminol chemiluminescence method to compare the results by the in-situ analyzer.

### Methods

#### Conventional method

Seawater samples were collected by X-Niskin samplers installed on the CTD-CMS system. Samples were immediately filtered with 0.2  $\mu\text{m}$  cartridge filter (Acropak, Pall) in a “bubble”. The seawater samples were injected to the flow analytical system (King and Lounsbury, 1995) after adjusting the pH of the samples at 6 (Hansard and Landing, 2009).

#### In-situ analytical method

The conventional luminol chemiluminescence method was adapted to an in-situ flow analytical system, GAMOS (Geochemical Anomalies MONitering System; Okamura et al., 2001). Sample was taken into the system and mixed with luminol reagent by a peristaltic pump. The mixture was introduced to a photomultiplier in a pressure-compensated vessel, and the CL intensity was recorded in the system. The device was lowered to a depth of 1000m, determining Fe(II) in seawater. After recovering the device onboard, we collected the Fe(II) data in the laboratory.

### Results

At the ER-2, 3, 5, 6, 7, 8, 9 and 10, we have revealed vertical profiles of Fe(II) in seawater. At ER-10, we have also determined Fe(II) in seawater by using an in-situ analyzer successfully

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## **8.20. Distributions and their speciation of trace metals in the Indian Ocean and Antarctic Ocean: GEOTRACES section study**

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### **1) Distributions of trace metals in the Indian Ocean and Antarctic Ocean**

#### **1-1) Objective**

Trace metals, such as Fe, Mn and Zn, are now thought to be essential for phytoplankton growth in the open oceans. However, large-scale distributions of trace metals have not been investigated yet in the Indian Ocean. To understand the controlling factors of trace metal concentrations, we need to investigate the detailed distributions of trace metals in the world ocean. In this study, we will study the distributions of dissolved trace metals (Fe, Mn, Zn, Al etc.) in the Arabian Sea, the Equatorial and South Indian Ocean and the Indian Ocean sector of the Antarctic Ocean, as the international GEOTRACES project.

#### **1-2) Samples**

Seawater samples for vertical profiles were collected using Teflon-coated X-type Niskin bottles mounted on a CTD/Carousel array. Filtered samples were obtained through a cleaned 0.2  $\mu\text{m}$  filter cartridge (Acropak, Pall) connected to sampler directly with pressured air. Filtered samples (500mL of PE bottle) are acidified to  $\text{pH} < 1.8$  with ultra pure HCl (Tamapure AA-100) and stored. Another set of samples is also stored in 500mL of PE bottles as archive samples.

#### **CTD sampling**

Station :ER-2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 14

Depth (m): 0, 25, 50, 100, 150, 200, 400, 600, 800, 1000, 1250, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, Bottom

#### **1-3) Analytical methods**

Iron will be determined by a flow analytical system by using chelating resin preconcentration and chemiluminescence (CL) detection (Obata et al., 1993; 1997), or cathodic stripping voltammetry (CSV) in the land-based laboratory. Manganese concentrations will be determined by a flow analytical system by using electrolytic column preconcentration and chemiluminescence (CL) detection (Nakayama et al., 1989). Zinc will be determined by cathodic stripping voltammetry (Ellwood et al., 2000) in the land-based laboratory. Aluminum will be determined by a flow analytical

system by Lumogallion fluorescent detection (Obata et al., 2001).

## 2) Trace metal speciation in the Indian Ocean and Antarctic Ocean

### 2-1) Introduction

Trace metals, such as Fe and Zn, are essential micronutrients for phytoplankton in the ocean. At low concentration levels, trace metals can limit the growth of marine phytoplankton in culture. Additionally, speciation is also considered to be an important factor of the biological availability of trace metals. However, little is known about the organic complexation of trace metals in open-ocean waters. In this study, we will investigate trace metal speciation in the Indian Ocean and Antarctic Ocean using cathodic stripping voltammetry (CSV).

### 2-2) Sample

Seawater samples were collected using Teflon-coated X-type Niskin bottles mounted on a CTD/Carousel array. Filtered samples were obtained through a cleaned 0.2  $\mu\text{m}$  filter cartridge (Acropak, Pall) connected to sampler directly with pressured air. Filtered samples (500mL of PE bottle) are frozen at -18°C and stored.

### CTD sampling

Station :ER-2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 14

Depth (m): 0, 50, 100, 200, 400, 600, 1000, 1500, 2000, 3000, 4000, 5000, Bottom

### 2-3) Methods

On the land-based laboratory, ligand concentrations and conditional stability constants for Zn and Fe will be obtained from a titration using CSV (Ellwood et al., 2000; van den Berg, 2006; Laglera and van den Berg, 2009).

## 8.21. Vertical Distribution of Re, Os and U in the Indian Ocean and the Southern Ocean

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**Objective:** The Southern ocean provides insight into the exchange of intermediate, deep and bottom waters between the Southern Ocean and subtropical Indian Ocean. Also, it is important with respect to Atlantic waters entering the Indian Ocean south of Africa and the transport of Southern Ocean water masses to the North. Prior studies of WOCE results along 30°S in the Indian Ocean have reported a substantial northward flow of deep water, and compensating return at intermediate depths. The studies on sources of iron from islands located within the Antarctica Circumpolar Circle and its biological response have revealed stimulation of phytoplankton growth by iron released from the islands and their surrounding sediments. This is expected to have effect on the internal cycling and distribution of the various trace elements and isotopes (TEIs) during redox conditions, e.g U, Re and Os and their isotopes which can also act as diagnostic tracer for provenance of water masses. The meridional fluxes of TEIs and ultimate quantification of the associated TEI fluxes is crucial for the identification of TEI sources and sinks in the Indian Ocean and the Southern Ocean.

**Sampling Technique:** Samples were collected from 12l Niskin sampler on a clean CTD rosette and were filtered through 0.2 mm filters (acropak) in a clean lab right after their collection. One liter of samples were collected from each depth for measurement of U, Re and Os and their isotopes and 1 ml of double distilled HNO<sub>3</sub> added to it. The samples are carried back to PRL for analyses.

**Measurement Technique:** The samples will be analysed for Os (isotopic composition  $^{187}\text{Os}/^{188}\text{Os}$  and concentration), Re and U concentrations after sample extraction and preparation in the clean lab at PRL. The measurements will be made on Thermal Ionization Mass Spectrometer for Os and on Inductively Coupled Plasma-Mass Spectrometer for Re and U after their extraction from seawater samples<sup>[1], [2]</sup>.

**Samples:** 1l of seawater samples from 22 depths each were collected at stations ER11, ER12 and ER14.

**References:**

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## 8.22. Chemical speciation of selenium in seawater in the Indian Ocean and Antarctic Sea

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### Purpose

Selenium exist three chemical forms such as selenite, selenate and organic selenide. Organic selenide was detected at deep water in the marginal seas such as the Sulu, the South China Sea and the Celebes Sea. The form of organic selenide was investigated by researching the relationship between marine humic-like fluorescence and organic selenide. There results confirmed that the organic selenide might be existed in the humic-like substances, and it is present in the deep water of South China Sea. Some results for organic selenide form indicated that the organic selenide might not be existed only seleno-amino acid form but also volatile form and humic-like substances form.

A new international programme in marine geochemistry, “GEOTRACES,” was started in 2005. The GEOTRACES mission includes determining the full water column distribution of selected trace elements and evaluating the sources and sinks and internal cycling of these species of the elements. However, the speciation and recycling of selenium in the western Indian Ocean and Antarctic Sea are still not well known. The present study describes the vertical profiles of dissolved selenium species and humic-like substances (fulvic acid) in the the Indian Ocean and Antarctic Sea during the cruise of *R/V Hakuho-Maru* in 2009.

### Sampling and Method

Seawater samples were collected by 12 L Teflon-coated Lever-action Niskin Bottles mounted on a 24-position Sea-Bird's 911 plus CTD-rosette, hung from a titanium-armored cable. The Niskin bottles were pre-cleaned successively with distilled HCl and deionized water. After collection, the water samples for selenium speciation were filtered through a 0.45- $\mu$ m nucleopore filter.

Determination of selenite: A 30-ml sample of filtered water was placed into a 100-ml glass beaker, and 5 ml of 0.1% 2,3-diaminonaphthalene (DAN, Nacalai Tesque Co. Ltd.) -0.1M hydrochloric acid solution and 0.5 ml of 0.1 M ethylenediaminetetraacetic acid-sodium fluoride (EDTA-NaF, Kishida Kagaku Co. Ltd.) solution were added to ask any interfering metal ions. The sample solution was adjusted to pH 1 with 6 M hydrochloric acid, and was warmed at 50°C for 20 min. After cooling, the solution was transferred to a separating funnel and was mechanically shaken with 5 ml of cyclohexane for 10 min. The piaselelol in the cyclohexane was determined by HPLC (high performance liquid chromatography) with a fluorescence detector at Ex. 375nm / Em. 520nm. The detection limit (S/N=2) of the DAN-HPLC method was 1 pM. Determination of selenate: The selenate amount was calculated by subtracting the selenite amount from the summed selenite and selenate amount, which was obtained by the following reduction procedure. A 20-ml filtered water sample was placed into a 100 ml

Erlenmeyer flask, and the acidity of the sample solution was adjusted to 1.2 M hydrochloric acid solution. After 2.0 g of potassium bromide was added, the flask was placed in a water bath and the solution was warmed at 85~90°C for 25 min. After cooling, the amount of reduced selenate and selenite in the solution was determined by HPLC. Determination of organic selenide: The amount of organic selenide was estimated by subtracting both the selenite and selenate from the total amount of selenium, which was determined after wet-ashing decomposition with conc. nitric and 60% perchloric acid (analytical grade), followed by HPLC



## 8.23. Helium isotopes of seawater in Indian Ocean and Southern Ocean

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### **Purpose**

$^3\text{He}/^4\text{He}$  ratio is one of the most sensitive and conservative tracer for studying the deep-sea circulation because 1)  $^3\text{He}$  in the ocean mainly derived from the mantle, 2) He is chemically inert gas. Even though  $^3\text{He}/^4\text{He}$  ratios are basic and important oceanographic data, there are not enough study in western Indian Ocean and Southern Ocean. In this study, deep seawaters are collected in the regions and their  $^3\text{He}/^4\text{He}$  ratios are measured. We discuss the deep-sea circulation based on the excess  $^3\text{He}$ .

### **Sampling method**

Seawaters were collected by CTD system and were transferred without exposure to atmosphere from Niskin bottle to ~30 cc copper container for helium isotopic measurement. Both ends of the copper containers were sealed with stainless clamp.

### **On land experiments**

At laboratory, the copper container is connected to a stainless steel high vacuum line and dissolved gases in seawater are extracted in vacuo. Helium in the extracted gases are purified by hot Ti-Zr getters and charcoal traps held at liquid nitrogen temperature. Helium is separated from neon by a cryogenic trap held at 40 K. After purifying and separating of helium,  $^3\text{He}/^4\text{He}$  ratios are measured on a noble gas mass spectrometer (VG 5400, MicroMass. Co.) with double collection mode. A resolving power of ~550 at 1% of peak height was used for the complete separation of  $^3\text{He}$  beam from those of  $\text{H}_3^+$  and  $\text{HD}^+$ . The  $^3\text{He}/^4\text{He}$  ratios of the samples are calibrated against atmospheric helium. Analytical error of  $^3\text{He}/^4\text{He}$  ratio is about 1 % estimated by repeated measurements of standard air.

## 8.24. Measurements of volatile halogenated and sulfur organic compounds in surface seawater

Atsushi Ooki, Yoko Yokouchi (National Institute for Environmental Studies)

### 1. Introduction

Various volatile organic compounds (VOCs) such as halocarbons and sulfur-containing compounds are emitted from the ocean surface into the atmosphere, and are believed to have substantial effects on the atmosphere. The partial pressures of VOCs were measured in the air of the marine boundary layer ( $p\text{VOC}_{\text{air}}$ ) and in surface seawater ( $p\text{VOC}_{\text{water}}$ ) during the cruise (KH09-5) from Leg1 to Leg3. We collected seawater samples by CTD observation, and measured vertical profile of VOCs concentrations.

### 2. Analysis

Surface seawater was pumped from a seawater intake on the bottom of the ship (5-m depth), and supplied to the laboratory. The surface seawater was continuously supplied to a silicone membrane tube equilibrator at a flow rate of  $15 \text{ L min}^{-1}$ . Pure air was continuously supplied to the silicone tubes at a flow rate of  $20 \text{ mL min}^{-1}$ , regulating the inner pressure to  $+0.14 \text{ MPa}$ . The gas-phase sample of VOCs at equilibrium with the seawater could be obtained from the outlet of the silicone tube. Outside air was drawn from the upper deck (17 m above the sea level) of the ship through a PTFE tube (length, 60m; i.d., 11 mm) at a flow rate of  $50 \text{ L min}^{-1}$ . We obtained a portion of the air from the PTFE tube at a flow rate of  $20 \text{ mL min}^{-1}$ . Seawater sample for depth profile measurement was collected from a Nyskin sampling bottle into a brown glass bottle with 124 mL volume. VOCs in seawater sample were purged with He carrier. The gas phase sample was dehumidified by means of Nafion<sup>®</sup> dryer and then transferred to a pre-concentration/GC-MS system. Partial pressures of  $\text{CH}_3\text{Cl}$ ,  $\text{CHClF}_2$ ,  $\text{CCl}_3\text{F}$ ,  $\text{C}_2\text{H}_2\text{F}_4$ ,  $\text{CCl}_2\text{F}_2$ ,  $\text{CH}_2\text{Br}_2$ ,  $\text{CHCl}_3$ ,  $\text{C}_2\text{Cl}_4$ ,  $\text{CH}_2\text{Cl}_2$ ,  $\text{C}_2\text{H}_5\text{I}$ ,  $\text{CH}_3\text{I}$ ,  $\text{CH}_2\text{ClI}$ ,  $\text{CHBr}_3$ ,  $(\text{CH}_3)_2\text{S}$  (DMS),  $\text{C}_5\text{H}_8$ ,  $\text{COS}$ , and  $\text{CH}_3\text{Br}$  in the sample were measured at 50–70 min intervals. A gravimetrically prepared standard gas (Taiyo Nissan, Inc., Tokyo) containing these chemical species at concentrations of 100–500 pptv was quantified according to the same procedures. The detection limits ( $S/N = 3$ ) were  $.1\text{--}1 \text{ pptv}$  for all species.

### 3. Results

Figure 1 shows the partial pressure of  $\text{CH}_2\text{Cl}_2$  in air ( $p\text{CH}_2\text{Cl}_{2\text{air}}$ ) and surface seawater ( $p\text{CH}_2\text{Cl}_{2\text{water}}$ ) during the cruise. High levels of  $p\text{CH}_2\text{Cl}_{2\text{air}}$  and  $p\text{CH}_2\text{Cl}_{2\text{water}}$  were found in the North Indian Ocean, apparently due to the influence of anthropogenic land sources.  $p\text{CH}_2\text{Cl}_{2\text{water}}$  was close to  $p\text{CH}_2\text{Cl}_{2\text{air}}$  during the cruise. The average  $p\text{CH}_2\text{Cl}_{2\text{air}}$  of 11.5 pptv would be a global background level in marine boundary air.

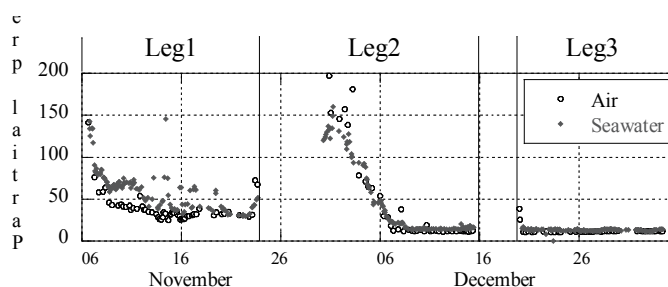


Figure 1 Partial pressure of  $\text{CH}_2\text{Cl}_2$  in air and surface seawater

## 8.25. Environmental Kinetics of Perfluorinated Acids in Water, Air, Precipitation and Sediment from the Indian Ocean and the Antarctic Ocean

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### Introduction

Environmentally persistent perfluorinated acids (PFAs, shown in figure 1) have appeared as a new class of global pollutants for the last ten years. These compounds in general, and perfluorooctane sulfonate (PFOS) in particular, have recently emerged as a priority environmental pollutant due to its widespread finding in biota including both Arctic and Antarctic species and its persistent and bioaccumulative nature. The physicochemical properties of PFAs are unique in that they have high water solubility despite the low reactivity of carbon-fluorine bond, which also imparts high stability in the environment. However, little is known on the distribution of PFAs in the oceans around the world, so far. We have conducted several international joint cruises, including South China Sea and Sulu Seas (KH-02-4), the central to Eastern Pacific Ocean (KH-03-1), North and middle Atlantic Ocean, Southern Pacific and Antarctic Ocean (KH04-5), Labrador Sea and coastal seawater from Asian countries (Japan, China, Hong Kong, Korea) (1, 2, 3). Vertical profiles of PFAs in the marine water column were associated with the global ocean circulation theory. Vertical profiles of PFAs in water columns from the Labrador Sea reflected the influx of the North Atlantic Current in surface waters, the Labrador Current in subsurface waters, and the Denmark Strait Overflow Water in deep layers below 2000 m. Striking differences in the vertical and spatial distribution of PFAs, depending on the oceans, suggest that these persistent organic acids can serve as useful chemical tracers to allow us to study oceanic transportation by major water currents. The results provide evidence that PFA concentrations and profiles in the oceans adhere to a pattern consistent with the global “Broecker’s Conveyor Belt” theory (3) of open ocean water circulation. However, it is not well known about Indian Ocean. The aim of this investigation is to understand three-dimensional distribution of PFCs in Indian Ocean; water, rain and sediment, and long-range atmospheric transportation of PFOS related chemicals.

### Materials and Methods

**Samples:** Seawater samples were taken by Conductivity temperature depth profiler-Carousel multiple sampling system (CTD-CMS) attached Niskin samplers of 12 L, together with surface seawater samples taken by stainless bucket at all the water sampling stations. At eleven sampling site, atmospheric materials taken with a high-volume air sampler (Shimadzu, HV-1000F). Particulate phase was collected on the quartz fiber filter, while gaseous phase was trapped in the XAD-2 resin and polyurethane foam slice. The air sampler was operated with a flow rate of 350 – 400 L/hr. Samples were collected during underway to avoid

contamination from exhaust gas from ship, except station ER10. Ambient air might be contaminated by exhaust gas from ship was also collected to evaluate possible influence for measurement at station ER10 during drifting. Rain samples were corrected by rain sampler (Shimadzu, w-102 and w-2s). 5 consecutive 100 mL rain samples (100 mL = 1 mm precipitation) were collected in 5 individual glass containers and then transferred to 100 mL of polypropylene bottles. Sediment core samples were taken by multiple corer at some stations. Each sediment core was sectioned for 1-2 cm segments using a stainless steel slicer. Water, air, rain and sediment samples were stored at below -20°C until chemical analysis in AIST laboratory.

### PFAs: per- and poly- fluorinated acids

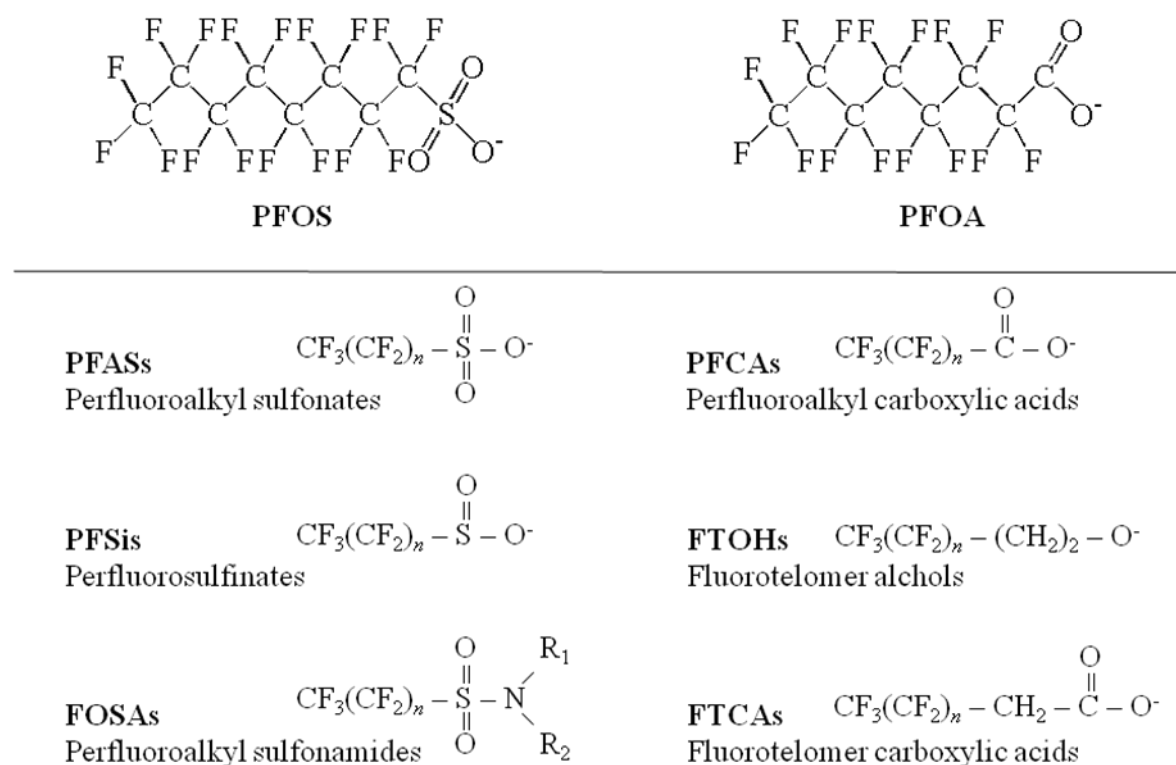


Figure 1. PFOS and related chemicals

**Chemical analysis:** Water samples were stored in clean 1 L polypropylene bottles and were kept frozen until analysis. Samples were thawed at room temperature, and a solid phase extraction method using WAX® cartridge (Waters Co.) was used for the determination of PFAs by HPLC tandem mass spectrometry (HPLC-MS/MS) as described elsewhere (4,5). Briefly, after preconditioning with 4 mL ammonium hydroxide in methanol, 4 mL methanol, and then 4 mL Millipore water, the cartridges were loaded with 900-1000 mL samples at approximately 1 drop sec<sup>-1</sup>. The cartridges were then washed with 4mL of 25 mM ammonium acetate buffer (pH 4) in Millipore water and dried by centrifugation at 3000rpm for 2 min. The elution was then divided into two fractions. The first fraction was carried out with 4 mL methanol and the second with 4 mL 0.1% ammoniumhydroxide in methanol. Both fractions were reduced to 0.5 mL under a nitrogen stream and analyzed separately. HPLC-MS/MS, composed of a

HP1100 liquid chromatograph (Agilent Technologies, Palo Alto, CA) interfaced with a Micromass® (Beverly, MA) Quattro Ultima Pt mass spectrometer was operated in the electrospray negative ionization mode. A 5 or 10-μL aliquot of the sample extract was injected into a Betasil C18 column (2.1 mm i.d.×50 mm length, 5μm; Termo Hypersil-Keystone, Bellefonte, PA). The capillary is held at 1.2 kV. Cone-gas and desolvation-gas flows are kept at 60 and 650 L/h, respectively. Source and desolvation temperatures were kept at 120 and 420°C respectively. MS/MS parameters are optimized so as to transmit the [M-K]- or [M-H]- ions.

More than two hundreds of PFOS related chemicals were discussed for international regulation of use, namely Stockholm convention agreement (POPs; persistent organic pollutants) in 2008 because of potential risk to the environment and human being. Finally, PFOS and PFOA were added to a list of international regulation in May 2009. Because of serious worldwide concern about PFOS, strong necessity to establish reliable standard operation procedure (SOP) were indicated. Hence, analytical method developed by AIST was validated by International Organization of Standard (ISO) and proved its reliability. This was successfully published as ISO25101 in 2009 (6). Brief summary of the round robin test (international calibration study) is as follows:

An international inter-laboratory trial was performed in February 2007. 24 laboratories from 9 countries took part (Australia: 1; Belgium: 1; Canada: 3; Germany: 7; Italy: 1; Japan: 2; Switzerland 1; United Kingdom: 2; United State of America: 6). PFOS and PFOA were analyzed in sea water (sample 1), river water (sample 2), matrix river water (sample 3), two concentrations of matrix distilled water (sample 4, sample 5) and standard in methanol solution (sample 6). Laboratories which didn't provide internal standard recoveries results were rejected as outliers. The results of internal standard recoveries didn't between 70% and 125% were rejected as outliers according to (9.2). The performance data are summarized in Table 1.

Table 1. Performance data of ISO25101

		$l$	$l_o$	$n$	$n_o$ %	$\bar{X}$ ng/l	$\eta$ %	$s_R$ ng/l	$CV_R$ %	$s_r$ ng/l	$CV_r$ %
Sea water (Sample 1)	PFOS	19	9	56	50	40,4	90	8,2	20,2	1,6	3,9
	PFOA	17	7	50	54	9,4	97	1,5	16,4	0,4	3,8
River water (Sample 2)	PFOS	19	6	55	42	9,1	90	2,4	26,8	0,3	3,8
	PFOA	18	7	54	39	18,7	91	3,7	19,5	0,6	3,0
River water with high concentration (Sample 3)	PFOS	16	10	48	65	469	96	92	19,6	20,6	4,4
	PFOA	16	8	48	54	4 440	91	976	22,0	186	4,2

Distilled water with low concentration (Sample 4)	PFOS	17	7	47	40	2,6	91	0,7	27,0	0,1	3,3
	PFOA	17	2	51	24	16,8	98	3,2	18,8	1,2	7,3
Distilled water with high concentration (Sample 5)	PFOS	18	5	55	31	47,8	96	7,7	16,1	2,1	4,4
	PFOA	18	5	54	33	359	96	55	15,5	18	5,0
$L$ is the number of laboratories; $l_o$ is the number of outlier laboratories; $N$ is the number of analytical values; $n_o$ is the percentage of outlier values; $\bar{X}$ is the mean of values after outlier rejection; $H$ is the mean of internal standard recovery; $s_R$ is the reproducibility standard deviation; $CV_R$ is the reproducibility coefficient of valuation; $s_r$ is the repeatability standard deviation; $CV_r$ is the repeatability coefficient of valuation.											

KH09-05 is the first international research cruise that conducted measurement of POPs in Open ocean waters using ISO method (ISO25101). Because of recent scene of analytical chemistry, uncertainty and reliability of measurement supported by suitable quality assurance and quality control (QAQC) becoming to the essential issue. Our experimental result with ISO25101 supported by the international QAQC (ISO17025 with Guide45) will provide the most reliable information of environmental chemistry in Open ocean research for now.

## Conclusion

Although everybody knows that the marine environment is three-dimensional, very few studies have investigated POPs including PFAs in deep sea water column. We have collected eleven water column samples, eleven ocean airs, more than seven rain events and six sediment cores during the cruise (figure 2). Recent report (3, 7) revealed that presence of PFCs in deep seawater shows the necessity of comprehensive survey including not only surface water but also vertical profile of PFCs in water column as well as open ocean air. The global circulation of ocean water and deep seawater might play a major role in scavenging of several POPs and therefore their role in the global fate of PFOS related chemicals must be examined to estimate the environmental destiny of persistent hazardous chemicals on our planet.

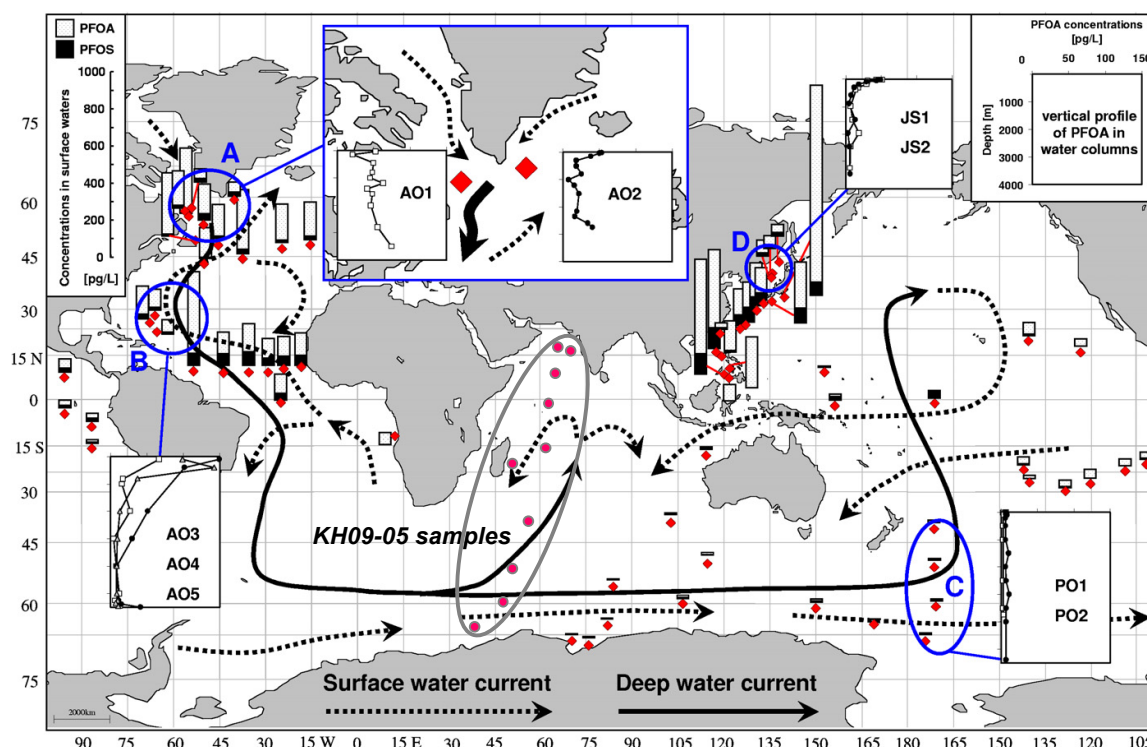


Figure 2. Concentrations of PFOS and PFOA in 62 surface-water samples and nine water-column samples collected from several oceans worldwide, with sampling locations in KH09-05.  
(modified from original figure by Yamashita, *Chemosphere* 2008).

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## **8. 26. Isotopic distributions of Nd and Ce in the Indian and Antarctic Oceans**

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### **1 Introduction**

Nd isotopic composition ( $^{143}\text{Nd}/^{144}\text{Nd}$ ), one of the useful isotopic tracers in geochemistry, is frequently utilized in the field of marine chemistry, because water masses show characteristic values reflecting the geology of Nd source area. Since the mean residence time of Ce is much shorter than that of Nd and other REEs, the less homogenized isotopic composition of Ce ( $^{138}\text{Ce}/^{142}\text{Ce}$ ) is expected to be a strong tracer for horizontal transport from the igneous province, such as the island arcs. In this cruise, we will determine the surface and vertical distribution for Ce and Nd ICs in the Indian and Antarctic Ocean.

### **2 Methods**

#### **2-1. Vertical profiles of Nd isotopic composition**

Seawater samples for vertical profiles of Nd IC were collected using a large volume water sampler (<2000m depth) and X-type Niskin samplers attached to CTD-CMS system (2500m-Bottom). Large volume samples (ca. 250L) were filtered with 0.5  $\mu\text{m}$ -pore size wind-cartridge filter (Advantec) and transferred to PVC bottles settled on the ship deck. Seawater (10-20L) from Niskin bottle was passed through the 0.2  $\mu\text{m}$ -pore size capsule filters, Acro Pak200 (Pall), with compressed air in the Bubble. Then HCl and Fe carrier (including Be carrier) were added. Nd was precipitated by  $\text{NH}_4\text{OH}$  with  $\text{Fe}(\text{OH})_3$ . The precipitates were filtered out by the qualitative filter paper ( $\phi 500\text{mm}$ : No.2, Advantec) and dryness for LV samples and cut down supernatant by decantation for Niskin samples, respectively. Then, samples were brought back to land based laboratory for further analysis.

#### **2-2. Vertical profiles of Ce isotopic composition**

Seawater samples for vertical profiles of Ce IC were collected at 5 layers



using a large volume water sampler in ER-10(Indian Ocean) and ER-14 (Antarctic Ocean). The sample volumes were 1000 L.

Sampling depth

ER-10: 100m, 600m, 1000m, 2000m, 4000m

ER-14: 100m, 600m, 1000m, 2500m, 5000m

Collected samples were transferred to PVC bottles settled on the ship deck after filtering 0.5 $\mu$ m pore size wind-cartridge filter (Advantec). Then, they were passed through MnO<sub>2</sub> fiber. Ce and Nd isotopes were strongly adsorbed on MnO<sub>2</sub> fiber. Further chemical separations and isotopic measurement are described in Tazoe et al. (2007).

### **2-3. REE concentrations**

Seawater samples for vertical profiles were collected using X-type Niskin bottles mounted on a CTD/Carousel array. Seawater from Niskin bottle was passed through the 0.2  $\mu$ m-pore size capsule filters, Acro Pak200 (Pall), with compressed air in the Bubble. Surface seawater samples were taken third a day from the ship's underway sampler and passed through the 0.5  $\mu$ m pore size wind-cartridge filter (Advantec). They are acidified to pH<1.8 with ultra pure HCl in the clean room (No.4 Lab.) and carried to the ORI for analysis using solvent extraction and ICP-MS (Shabani et al., 1990).

### **2-4. Distributions of Ce and Nd ICs and REE concentrations**

In addition of vertical sampling, surface seawaters were also collected for terrestrial input, such as river and aerosol, and lateral transportation by surface current system. Ce IC requiring large volumes (>1000L) were collected at station, and Nd IC were collected 50 – 100L of seawater every 8 hours during cruise. Surface seawater samples were taken from the underway sampler and passed through the 0.5  $\mu$ m pore size wind-cartridge filter (Advantec) and by the MnO<sub>2</sub> method mentioned above. Both Ce and Nd isotopes dissolved in seawater were strongly adsorbed on the fiber.

## 8. 27. Distributions of cosmogenic $^7\text{Be}$ , $^{10}\text{Be}$ in the Atmosphere and Ocean

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### Purpose

Beryllium-7(53.3d) and -10( $1.5 \times 10^6$ y) are produced in the atmosphere by cosmic rays. The production rates are dependent on latitude, altitude and time, because the intensity of the cosmic rays is not homogeneous. These nuclides are transported by aerosols, and move from the stratosphere to the surface soil and surface ocean via the troposphere. The distribution of production rates and precipitation rates of these nuclides were calculated by Lal and Peters (1964), but their calculation has not been confirmed experimentally. The purpose of this study is to obtain information on the concentration and transportation of Be isotopes in the atmosphere and ocean. This study consists of four parts:

- 1) latitudinal distribution of cosmogenic  $^7\text{Be}$  and  $^{10}\text{Be}$  in the atmosphere,
- 2) precipitation rates of  $^7\text{Be}$  and  $^{10}\text{Be}$ , from the atmosphere to the ocean surface,
- 3) transportation of Be isotopes in the ocean surface layer,
- 4) depth profiles of  $^7\text{Be}$  and  $^{10}\text{Be}$ , from the surface to the bottom of the water column.

### Method

#### 1. Air

Atmospheric Be isotopes attached to aerosols were continuously collected on a filter paper (Whatman 41, 25x10 cm) using a high volume air sampler (Kimoto Electric Co. LTD., AS-1400), which was installed on the upper deck. Typical sampling time was 2 days, and flow rate was 1m<sup>3</sup>/min. The  $^7\text{Be}$   $\gamma$ -ray measurements of the filter papers will be made without any chemical treatment.

#### 2. Seawater

To recover Be isotopes from large volume (250L) seawater samples above 2000m depth, 2 mg of Be carrier, 2g of Fe carrier and 250ml of conc. HCl were added. After 3 hours or more later, 250ml of conc. NH<sub>4</sub>OH were added to the solution to co-precipitate Be(OH)<sub>2</sub> and Fe(OH)<sub>3</sub>. After discarding most of the supernatant, the precipitate was filtered onto a filter paper (Advantec No.2,  $\phi$ 50cm). Precipitates of Be(OH)<sub>2</sub> and Fe(OH)<sub>3</sub> were leached by conc. HCl from the filter paper, then concentrated and adjusted to 9M HCl solutions by adding conc. HCl for isopropyl ether extraction. Extraction procedure was repeated 3 times

to remove Fe. Finally, 10mg of Fe(III) was added to the solution, and reprecipitated by conc.  $\text{NH}_4\text{OH}$  to obtain a small amount of  $\text{Be}(\text{OH})_2$  and  $\text{Fe}(\text{OH})_3$ , which was filtered onto a 47mm  $\phi$  membrane filter for  $^7\text{Be}$   $\gamma$ -ray measurement. Below 2000m depth, seawater (10-20L) from Niskin bottle was passed through the 0.2  $\mu\text{m}$ -pore size capsule filters, Acro Pak200 (Pall), with compressed air in the Bubble. Seawater was concentrated by Fe coprecipitation and removed Fe by solvent extraction, as well as large volume sample. The purification for  $^{10}\text{Be}$  AMS measurement will be made using a cation exchange column. For  $^9\text{Be}$  measurements, 250 ml of filtered seawater samples were separately stored in polypropylene bottles at seawater sampling.

#### *4. Measurements of Be isotopes*

Measurements of Be-7, 9 and 10 will be made with a HP Ge  $\gamma$ -ray detector, ICP-MS and AMS at MALT, Univ. of Tokyo, respectively.

## 8.28. Determination of Ir, Pt, Ru and Pd in seawater

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### 1) Objective

Iridium and the other platinum group elements (PGEs) are used as tracers of extraterrestrial material because these elements are enriched in meteorites relative to Earth's crust. The high concentration of Ir in sediments and rocks at the Cretaceous-Tertiary (K-T) boundary is thought to be the result of an extraterrestrial impact that caused mass extinction.

Understanding the aqueous geochemistry of Ir is important because most sediment are deposited in aquatic environments and may be subject to aqueous alteration after deposition. Two reasons can be pointed out for such a scarcity in data for PGEs in seawater. Firstly, the concentrations of these elements are considered to be less than 1 pmol/L. Secondly, the convenient and high sensitivity method for determining these elements has not been developed yet.

### 2) Method

#### 2-1) Onboard

Seawater samples for vertical profiles were collected using X-type Niskin bottles mounted on a CTD/Carousel array. Seawater from Niskin bottle was passed through the 0.2 µm-pore size capsule filters, Acro Pak200 (Pall), with compressed air in the Bubble. Surface seawater samples were taken third a day from the ship's underway sampler and passed through the 0.5 µm pore size wind-cartridge filter (Advantec). They are acidified to pH<1.8 with ultra pure HCl in the clean room (No.4 Lab.) and carried to the ORI for analysis using.

The seawater samples for PGEs determination were collected the following depths.

Depth (m): 0, 10, 25, 50, 100, 150, 200, 400, 600, 800, 1000, 1250, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, Bottom

#### 2-2) After the cruise

The mixed spike solution consists of <sup>191</sup>Ir spike, <sup>195</sup>Pt spike, <sup>101</sup>Ru spike and <sup>105</sup>Pd. It is difficult for PGEs in seawater to achieve isotopic equilibrium with added spikes, if the PGEs in seawater complex with organic matter. Three procedures, a) bubbling Cl<sub>2</sub> gas, b) acidified by HCl and add H<sub>2</sub>O<sub>2</sub>, c) exposing UV-ray, will be

applied to the samples collected during this cruise. And then, Fe carrier and ammonia solution are added successively to form  $\text{Fe}(\text{OH})_3$ , which coprecipitates many kind of metal ions dissolved in the sample. One or two days later, the  $\text{Fe}(\text{OH})_3$  precipitate is collected and dissolved in diluted HCl and added with an oxidizing reagent. Each PGEs are separated using an anion exchange column. .

The isotopic ratios of the purified PGEs are determined using Finnigan MAT 262 in N-TIMS mode. The purified Ir and Ru are loaded on degassed platinum filaments with 20mg of Ba in nitric form. Measured ion species of Ir and Ru are  $\text{IrO}_2$  and  $\text{RuO}_3$ , respectively. The isotopic ratios are determined using an ion counting system. On the other hand, Pd and Pt are determined using inductively coupled plasma mass spectrometer (ICP-MS). The concentrations of these elements are calculated by the measured isotopic ratios using the equation for isotope dilution method.

## 8.29. Tracing Nitrogen Cycles in Indian and Antarctic Ocean

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### Purpose:

Nitrate is a dominant source of new production in euphotic zone. The primary purpose of this study is to clarify the nitrogen cycles in the oceans of Indian and Antarctic using the stable isotopic compositions of nitrate ( $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$ ), as well as the triple oxygen isotopic compositions ( $\Delta^{17}\text{O} \approx \delta^{17}\text{O} - 0.52 \times \delta^{18}\text{O}$ ). By using the stable isotopic compositions of nitrate, we can trace both origin and fate of nitrate, because we can differentiate those from atmosphere and from deep water. Besides, we also determined following key parameters that are essential to quantify nitrogen cycles in the oceans: nitrogen fixation rates, both concentrations and stable nitrogen isotopic compositions of particulate organic nitrogen (PON), dissolved organic nitrogen (DON), and nitrous oxide, and the stable isotopic compositions of oxygen.

### Methods:

Samples for nitrate, PON, and DON

Water samples were filtered through the GF/F filter (0.7  $\mu\text{m}$  pore size) under gentle vacuum to gather PON on the filter. The filter was then frozen in a plastic case immediately afterwards until analysis. The filtrate water samples were collected in a light-resistant polyethylene bottle and frozen to analyze both nitrate and DON.

To determine the stable isotopic compositions,  $\text{NO}_3^-$  is chemically converted to  $\text{N}_2\text{O}$  using a method originally developed for  $^{15}\text{N}/^{14}\text{N}$  and  $^{18}\text{O}/^{16}\text{O}$  isotope ratios, and  $\delta^{15}\text{N}$ ,  $\delta^{18}\text{O}$  and  $\Delta^{17}\text{O}$  values were determined using the automated multiple analytical system based on CF-IRMS.

CTD sampling

Station: 5,6,7,8,9,10,11,12,14

Depth (m): 0, 5, 10, 25, 50, 100, 150, 200, 400, 600, 800, 1000, 1250, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, bottom.

Samples for nitrous oxide and oxygen

Subsamples for  $\text{N}_2\text{O}$  and oxygen analysis were transferred to 120 or 250 ml vials, poisoned with saturated  $\text{HgCl}_2$  solution, and sealed with septum caps without headspace.

CTD sampling

Station: 5,6,7,8,9,10,11,12,14

Depth (m): 0, 5, 10, 25, 50, 100, 150, 200, 400, 600, 800, 1000, 1250, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, bottom.

#### Samples for nitrogen fixation rates

Water samples were incubated in 500-ml Polycarbonate bottles sealed with a septum cap (Teflon-lined butyl rubber). A gas-tight syringe was used to inject 1.0-ml of  $^{15}\text{N}_2$  (99 atom%, Shoko Co. Ltd., Japan) into the bottle and then to withdraw a 1.0 ml volume of solution to equalize the pressure across the septum. The sample bottles were gently mixed and then incubated in thermostatic baths on a deck covered with screens simulating the in situ temperature and in situ light intensity for periods ranging between 12 to 48 hours. At the end of each experiment, the suspended particles in each bottle were collected and stored in a same manner with the ordinary natural PON samples. On the other hand, filtrate water were collected and stored in a same manner with the natural DON samples.

#### CTD sampling

Station: 5,8,10,11

Depth (m): 0, 10, 50, 100

### **8.30. Measurement with quick response oxygen sensor RINKO during KH-09-5 leg3 cruise**

Daisuke Sasano and Masao Ishii

Geochemical Research Department, Meteorological Research Institute

#### **(1) Objectives**

The oxygen sensor “RINKO” which was recently developed by JFE Alec Co. Ltd. has a quick response. Because a quick response can reduce time-integrated effect of last observation history, it is potentially applicable to shipboard continuous vertical observations with CTD; the result of observation by RINKO is expected to be closer to true DO profile. In particular this feature is critical in a cold water region because a response time becomes slow in low temperature.

In this cruise, we used RINKO in hydrographic observations in the Indian Ocean and Antarctic Ocean. On the basis of the results, we evaluate its performance and more detailed structures of DO profiles.

#### **(2) Methods**

RINKO was mounted on CTD (SBE 911plus system, Sea-Bird Electronics, Inc) on CTD/carousel multi-sampler during KH09-5 leg3 cruise.

After cruise, the raw output of RINKO is converted to the DO concentration using the bottle data of DO measured.



### 8.31. Measurements of oceanic pCO<sub>2</sub> and pO<sub>2</sub> during KH-09-5 cruise

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#### (1) Objectives

The ocean plays an important role in determining the atmospheric CO<sub>2</sub> level, which has been currently increasing due to human activities (IPCC, 2001). Because of the large surface area and regional wind velocity, the Southern Ocean is considered to be an area showing a large CO<sub>2</sub> flux between the sea and the air (Sabine and Key, 1998). Furthermore, water formed in the Southern Ocean ventilates the intermediate and abyssal depths of much of the world's oceans (Rintoul and Bullister, 1999).

On the basis of measurements of the difference in the partial pressure (fugacity) of CO<sub>2</sub> between the sea and the overlying air ( $\Delta p\text{CO}_2$ ), CO<sub>2</sub> uptakes in the Southern Ocean south of 50°S were estimated to be in the range of 0.2 to 0.6 Pg-C/yr (Tans et al., 1990; Takahashi et al., 1997; 1999), while atmospheric inverse models, which use spatial distributions of atmospheric CO<sub>2</sub> for inferring surface CO<sub>2</sub> fluxes, gave lower atmospheric CO<sub>2</sub> uptakes of about 0.1 Pg-C/yr (Rayner et al., 1999). Takahashi et al. (2002) reported that the uptake of the Southern Ocean (south of 50°S) is larger than 20% of the total, although it occupies about 10% of the global ocean. More recently, they however, reported the smaller uptake of CO<sub>2</sub> (0.05 Pg-C yr<sup>-1</sup>) by adding  $\Delta p\text{CO}_2$  data taken over 2000s (Takahashi et al., 2009). As a matter of fact, most  $\Delta p\text{CO}_2$  measurements are made only in the Austral summer (see, for example, Metzl et al., 1999), which is insufficient to elucidate the annual CO<sub>2</sub> uptake in the Southern Ocean. Even in summer season, there have been differences in phase and amplitude of  $\Delta p\text{CO}_2$  in the Southern Ocean (Takahashi et al., 2009).

A lower value of oceanic uptake close to that of the atmospheric inversion model and ocean inversion model (Gloor et al., 2003) has been estimated by adding the observed  $\Delta p\text{CO}_2$  data in the Austral winter (Metzl, after Fig. 1 of Roy et al., 2003). This does not reconcile the numerical model result of a small Southern Hemisphere CO<sub>2</sub> uptake with the observations because numerical model studies that examined the distributions of CO<sub>2</sub> sources and sinks have large uncertainties in estimating the regional CO<sub>2</sub> sources and sinks (Sabine and Key, 1998).

In this cruise, we made concurrent underway measurements of CO<sub>2</sub>/O<sub>2</sub> concentration in the atmosphere and in surface seawater. The objective of these observations is to describe the oceanic CO<sub>2</sub> system in the Southern Ocean and to clarify the effect of biological activities on the surface carbonate system, which is one of the controlling factors that are responsible for variations in air-sea

CO<sub>2</sub> flux, as well as to determine the log-term change in the oceanic CO<sub>2</sub> due to the anthropogenic CO<sub>2</sub> accumulation in the ocean.

## (2) Methods

Underway measurements of CO<sub>2</sub>/O<sub>2</sub> concentrations in marine boundary air and in the air equilibrated with surface seawater:

We made measurements of the CO<sub>2</sub> and O<sub>2</sub> concentrations in the dry air equilibrated with the great excess of surface seawater ten times every 2 hour during the whole cruise using the automated CO<sub>2</sub> measuring system (Nippon ANS Co.). Seawater was taken continuously from the seachest located ca.5 m below the sea level and introduced into the MRI-shower-type equilibrator. Non-dispersive infrared (NDIR) gas analyzer (LI COR 6252) and oxygen analyzer (Sable Systems Oxzilla II) were used as detectors. We used four CO<sub>2</sub> reference gases (306ppm, 356ppm, 405ppm, 456ppm in air, Nippon Sanso Co.) once every 2 hour. Concentration of CO<sub>2</sub> will be published on the basis of the WMO X85 mole fraction scale after the cruise. With respect to concentration of dissolved O<sub>2</sub>, O<sub>2</sub> concentration in the ambient air will be used as a reference. Corrections for the temperature-rise from the seachest to the equilibrator are also to be made. Partial pressure of CO<sub>2</sub> and O<sub>2</sub> will be calculated from  $x\text{CO}_2$  and O<sub>2</sub> by taking the water vapor pressure and the atmospheric pressure into account.

## (3) Results

Data analyses have not been completed. We describe the results only briefly.

CO<sub>2</sub> concentration ( $x\text{CO}_2$ ) in marine boundary air and in the air equilibrated with surface seawater ranged from 250 to 410 ppm. In the Southern Ocean south of 60°S, the ocean acted as a sink for atmospheric CO<sub>2</sub>, which agreed fairly well to the pCO<sub>2</sub> data taken in the same time measured in early 2000s. O<sub>2</sub> concentration in surface seawater increased largely with decreases in pCO<sub>2</sub> in surface seawater, suggesting the onset of phytoplankton blooming. These data will allow us to evaluate the net community production in this area.

## (4) Data archive

The original data will be archived at Graduate School of Environmental Science/Faculty of Environmental Earth Science, Hokkaido University and Division of Geochemistry, Meteorological Research Institute. Data will be also submitted to the JODC and WMO WDCGG within 3 years.

### 8.32. Distributions of TCO<sub>2</sub> and TA during KH-09-5 leg3 cruise

Daisuke Sasano and Masao Ishii

Geochemical Research Department, Meteorological Research Institute (MRI)

#### (1) Objectives

The Southern Ocean, where the North Atlantic Deep Water upwells at the Antarctic Divergence zone, the Antarctic Bottom Water sinks on the continental slope and the Antarctic Intermediate Water and the Antarctic Mode Water subduct equatorward in the lower latitudinal zone, is considered as one of the critical zones in uptaking the anthropogenic CO<sub>2</sub> from the atmosphere and transporting it into the interior of the ocean. In addition, the uptake and transport of anthropogenic CO<sub>2</sub> here is expected to be vulnerable to the climate change. We have been synthesizing the data of water column CO<sub>2</sub> and its related parameters in connection with the EU integrated project CARBOOCEAN and CLIVAR-IOC International Ocean Carbon Coordination Project in order to understand the long-term change in the carbon cycle in the Southern Ocean. The synthesized dataset of CARINA that is subjected to the 2<sup>nd</sup> level quality control included those data we have taken in the past R/V Hakuho Maru cruises in the Southern Ocean. However, number of data here is still limited.

By combining with the CARINA dataset, water column CO<sub>2</sub> data taken in this cruise will also be used for the analysis of the long-term carbon cycle change as well as to understand the dominant controlling factors of *p*CO<sub>2</sub> and *p*O<sub>2</sub> in surface waters.

#### (2) Parameters

Total inorganic carbon (TCO<sub>2</sub>) in the water column.

Total alkalinity (TA) in the water column.

#### (3) Methods

Discrete samples for TCO<sub>2</sub> and TA were taken from Niskin bottles on CTD/carousel sampler and from a bucket for surface seawater at the total of 3 hydrographic stations (ER11, ER12 and ER14).

Samples for TCO<sub>2</sub> and TA analyses were collected in 250 cm<sup>3</sup> borosilicate glass bottles (Schott Duran) with ground-glass stopcock lubricated with Apiezon L grease, and were poisoned with 0.2 cm<sup>3</sup> of saturated HgCl<sub>2</sub> solution. They will be sent to the MRI immediately after coming back to Harumi, Tokyo. TCO<sub>2</sub> and TA will be determined simultaneously by the coulometry and spectrophotometry, respectively, using an automated TCO<sub>2</sub> – TA analyzer (Nippon ANS). They are

standardized using a suite of  $\text{Na}_2\text{CO}_3$  solution and the reference seawaters that are traceable to the CRM provided by Dr. A. Dickson in Scripps Institution of Oceanography. A correction for the addition of  $\text{HgCl}_2$  solution is to be made.

### **8.33. Vertical profiles of Nd isotopic composition in the South Indian and Antarctic Oceans**

**Hiroshi Amakawa**

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Nd isotopic composition of seawater, which is chosen as a key parameter of GEOTRACES project, has been intensively studied in the Atlantic, Pacific and Arctic Oceans. However, in the South Indian Ocean, available Nd isotopic composition data is limited, partly due to a bad access from both Europe and US. The aim of this study is to clarify vertical distributions of Nd isotopic composition in the Indian and Antarctic Oceans and elucidate the water circulation in the global ocean.

I collected the water samples at the stations in the Southwest Indian Ocean along in the Antarctic Ocean (ER-11, 12, and 14) using a large volume water sampler together with a CTD-CMS. The sample volumes were 20L for above 2000m and 10L for below 2500m. The water samples were transferred to acid pre-cleaned containers and added with HCl and Fe ( $\text{Fe}^{3+}$ ). After more than 4 hours, ammonia solution was added to make  $\text{Fe}(\text{OH})_3$  for coprecipitating rare earth elements including Nd.

#### **Sampling**

Station: ER-11, 12, and 14

Depth: 10m, 100m, 200m, 400m, 600m, 800m, 1000m, 2000m, 2500m, 3000m, 4000m, 5000m, Bottom

In a shore-based laboratory,  $\text{Fe}(\text{OH})_3$  is separated from the samples and dissolved in 6M HCl. Then, rare earth element fraction is separated and purified from the solution using anion and cation exchange columns. Finally, Nd fraction is further separated and purified from the rare earth fraction by using a reverse phase chromatographic column (Ln resin column, LN-C50-A, provided by Eichrom Technologies Inc.). Nd isotopic composition is determined by Finnigan MAT 262 thermal ionization mass spectrometer installed at Ocean Research Institute, University of Tokyo.

I also collected 1L seawater for Nd concentration measurement.

### 8.34. Distributions of dissolved gasses in the Indian Ocean and Antarctic Ocean

Noriko Nakayama, Takeshi Ogura and Toshitaka Gamo

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1) A simultaneous onboard measurement of dissolved O<sub>2</sub>/Ar/N<sub>2</sub> ratios by using a quadruple mass spectrometer in the Indian Ocean

Simultaneous measurements of the dissolved O<sub>2</sub>/Ar/N<sub>2</sub> ratio of the mixed layer, allow one to constrain the basic metabolic processes (photosynthesis, respiration, and net production). Dissolved O<sub>2</sub>/Ar is indicative of net production, because O<sub>2</sub> and Ar share similar solubility properties with respect to physical mechanism, but only O<sub>2</sub> is biologically influenced. Aculeate measurements of N<sub>2</sub> and Ar saturations are also important to a variety of other geochemical application. N<sub>2</sub>/Ar ratios of the ocean yield estimates of excess N<sub>2</sub> produced during denitrification. We have achieved an advance (improved precision) for measuring the concentration of dissolved O<sub>2</sub>/Ar/N<sub>2</sub> by building a quadruple mass spectrometer. It was successfully deployed onboard for the first time in the Indian Ocean.

Methods: Seawater samples were collected from X-type Niskin bottles mounted on a CTD/Carousel array. Approximately 100ml sea water samples were taken in 300 ml bottles poisoned with 250  $\mu$ l of saturated HgCl<sub>2</sub> solution to impede biological activity after sampling and evacuated prior to the sampling[1]. During sampling the flasks were filled taking extreme care to avoid introducing atmospheric gas in bubbles. This was accomplished by attaching a 50-cm long polyethylene tube with a Koshin-Rika Inc. Ultra-torr glass valve.

Samples: 12 to 18 of seawater samples collected at stations ER2 to ER10.

#### Reference

[1] Hamme R. and S. Emerson, *Geophys. Res. Lett.*, **29**(23), 2120, 2002.

2) Triple isotope composition of dissolved oxygen and their relation with oceanic productivity in the Indian Ocean and Antarctic Ocean

Most biological processes fractionate O isotopes in a mass-dependent way, such that <sup>17</sup>O enrichment is about half of <sup>18</sup>O enrichment relative to <sup>16</sup>O. As a result,  $\delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  in atmospheric O<sub>2</sub> plot along a line with a mass-dependent slope of about 0.52 (we use the standard delta notation in units of per mil:  $\delta^*\text{O} = (X^*/X^*_{\text{std}} - 1)10^3$ . Here \*O is either <sup>17</sup>O or <sup>18</sup>O and X\* is the isotopic ratio (\*O/<sup>16</sup>O) of the sample. X\*<sub>std</sub> is the isotopic ratio of the standard, which will be atmospheric O<sub>2</sub> in this study.) Marine photosynthesis produces O<sub>2</sub> that has the same isotopic composition as seawater [1],  $\delta_w^{18}\text{O} = -22.960\text{‰}$ .

This is  $\delta^{18}\text{O}$  of Standard Mean Ocean Water (SMOW) with atmospheric  $\text{O}_2$  as the standard [2]. Addition of photosynthetic  $\text{O}_2$  thus causes an increase in  $[\text{O}_2]$  and a decrease in  $\delta_{\text{dis}}^{18}\text{O}$ . The  $^{18}\text{O}/^{16}\text{O}$  ratio of  $\text{O}_2$  consumed by respiration is lower than the  $^{18}\text{O}/^{16}\text{O}$  ratio of the dissolved  $\text{O}_2$ . Respiration therefore causes  $\delta_{\text{dis}}^{18}\text{O}$  to rise in the residual dissolved  $\text{O}_2$ , while it lowers  $[\text{O}_2]$ .

In contrast to these mass-dependent processes, ultraviolet (UV)-induced interactions among  $\text{O}_2$ ,  $\text{O}_3$ , and  $\text{CO}_2$  in the stratosphere cause mass-independent fractionation with equal lowering of  $\delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  in atmospheric  $\text{O}_2$  [3]. Therefore, for a given  $\delta^{18}\text{O}$  of  $\text{O}_2$  produced solely by biological production and consumption, there is an excess of  $^{17}\text{O}$  in comparison to air  $\text{O}_2$ . This  $^{17}\text{O}$  excess ( $\Delta^{17}\text{O}$ ) with respect to air  $\text{O}_2$  is defined as  $\Delta^{17}\text{O} = 10^3(\delta^{17}\text{O} - 0.521\delta^{18}\text{O})$ . By definition,  $\delta^{18}\text{O}$ ,  $\delta^{17}\text{O}$ , and  $\Delta^{17}\text{O}$  of air  $\text{O}_2$  equal zero. The  $\Delta^{17}\text{O}$  value of dissolved  $\text{O}_2$  ( $\Delta_{\text{dis}}$ ) depends on the rate of air-water gas exchange, which tends to bring  $\Delta_{\text{dis}}$  to an equilibrium value with air, and the rate of in situ production of biological  $\text{O}_2$ , which tends to increase  $\Delta_{\text{dis}}$  to a maximum value of pure biological  $\text{O}_2$ . In natural aquatic systems,  $\Delta_{\text{dis}}$  varies between these two extremes, and its value depends on the ratio of the rates of gross primary production and air-sea  $\text{O}_2$  exchange. Thus, gross production can be calculated from  $\Delta_{\text{dis}}$  if the rate of air-sea gas exchange is known.

Methods: Approximately 100ml sea water samples from CTD cast were taken in 300 ml bottles that had been poisoned with 250  $\mu\text{l}$  of saturated  $\text{HgCl}_2$  solution to impede biological activity after sampling and evacuated prior to the sampling. In order to avoid the long storage of samples in vacuum bottles, samples were equilibrated onboard, and the water was extracted [4] and transferred onto molecular sieve in the glass tube [5]. The triple isotope composition of dissolved oxygen will be determined by an isotope ratio mass spectrometer (Delta<sup>Plus</sup>XP; Thermo Finnigan) in the land-based laboratory.

Samples: 12 to 18 of seawater samples collected at stations ER2 to ER14.

#### References

- [1] Guy, R. D., M. L. Fogel, and J. A. Berry, *Plant Physiol.*, **101**(1), 37– 47, 1993.
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### 8.35. Uranium and thorium decay series isotopes in Indian Ocean

Taejin Kim, Hajime Obata, Toshitaka Gamo

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#### Introduction

$^{230}\text{Th}$  and  $^{231}\text{Pa}$  are produced in seawater at a constant rate from the decay of dissolved uranium isotopes. Both are rapidly scavenged from the water column into the underlying sediments, resulting in large  $^{230}\text{Th}$  and  $^{231}\text{Pa}$  deficits in the water column and large excesses in the sediments.  $^{230}\text{Th}$  is more particle-reactive with very short residence times in the water column (ranging from  $<1$  yr in surface water to a few decades in deep water) than  $^{231}\text{Pa}$ , which limits redistribution by horizontal transport. In contrast,  $^{231}\text{Pa}$ , with a larger residence time in water column (up to 200 yr in deep water), is more effectively transported and scavenged in the regions with high productivity and particle flux. In this study we will obtain the vertical profiles of  $^{230}\text{Th}$  and  $^{231}\text{Pa}$ , and reveal the horizontal transport process and scavenging intensity of both nuclides in this area.

#### Methods

Seawater samples were collected by X-Niskin samplers installed on the CTD-CMS system and filtered through  $0.2\ \mu\text{m}$  cartridge filter (Acropak, Pall) in a “bubble”. The filtered samples were transferred into 10L polyethylene bottles and acidified with 68%  $\text{HNO}_3$  (Tama pure AA-100, Tama chemicals). The water samples will be spiked by  $^{229}\text{Th}$  (~500fg),  $^{236}\text{U}$  (~60ng),  $^{233}\text{Pa}$  (~70fg) and will be extracted to U, Th, Pa, respectively. These samples will be measured by Inductively Coupled Plasma-Mass Spectrometer.

#### References

A.L. Thomas et al., Earth and Planetary Science Letters 241(2006) 493-504



### 8.36. Distribution of oxygen stable isotope in the Indian Ocean and Southern Ocean

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The oxygen isotopic composition of water is widely used as tracers in oceanographic and climate study. The distribution of  $\delta^{18}\text{O}$  in ocean waters is controlled primarily by the hydrological cycle, reflecting the ratio of evaporation and precipitation acting on surface water masses, the amount of fresh water input from continent and the amount of meteoric water stored in continental ice. The stable oxygen isotopic compositions of foraminiferal carbonate reflect the isotopic composition of oceanic water masses. Therefore, foraminiferal  $\delta^{18}\text{O}$  values are used as proxies for temperature and salinity of oceanic water masses, to reconstruct past ocean circulation pattern and past climates. Here I am focusing on interpretation of analyses of stable isotope of oxygen in seawater with the aim to contribute to better understanding of water mass in vertical and along a longitudinal section in the Indian Ocean and Southern Ocean.

#### **Methods**

Sampling from Indian Ocean and Southern Ocean was performed at 11 stations from ER-2 to ER-14 except ER-4 & 13 during this cruise. Seawater samples of ~25 cc were taken in brown bottles with inner caps. After sampling, the bottles turning upside down were stored in the dark condition. The  $^{18}\text{O}/^{16}\text{O}$  ratios measured by the conventional  $\text{CO}_2\text{-H}_2\text{O}$  equilibration method (Epstein and Mayeda, 1953) will be determined with a mass spectrometer with dual inlet system (IsoPrime) in Kochi University.

Epstein, S., Mayeda, T. K., 1953. Variation of  $^{18}\text{O}$  content of waters from natural sources. *Geochim. Cosmochim. Acta* 44, 213–224.

### **8.37. Biogeochemical and paleoceanographic studies on Ba in seawaters and sediment cores from the western Indian and Antarctic Oceans; GEOTRACES section study**

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School of Biological Science and Engineering, Tokai University

Barite ( $\text{BaSO}_4$ ) has been found in suspended and settling particles in seawaters, and also in sea-floor sediments under high productivity regions. It is believed that barite particles are formed in settling particles during the biological process. Therefore, the distribution of barite or biogenic Ba (as the excess amount relative to the crustal abundance) in the sediment core is useful as a proxy for the change of paleo-productivity. While, it is important for us to understand the biogeochemical cycles of Ba, the uptake in the euphotic zone and the regeneration in the deep-water. And also, we must know about the early diagenesis of sedimentary Ba through its distribution in the pore water and solid phase of sediment core. The purposes of this research are divided into three categories; (1) to clear the distribution of Ba in seawaters in the western Indian Ocean, (2) to understand the diagenetic recycle of Ba in the sediment core, and (3) to evaluate the change of ocean fluxes of biogenic Ba, carbonate and opal during the last glacial age, comparing between the Arabian Sea to the Antarctic Ocean.

#### **1. Ba in seawater**

It is known that the vertical distribution of Ba in seawater is very like that of silicate. However, the correlation between the two is less than that between Ba and the silicate/nitrate ratio (Si/N). Previously, we have found out the linear relationship between Ba and Si/N in the central Pacific section study from 50°N to 67°S in 2009. There is very possibility of using this relation as a paleoceanographic tool, as well as the case of the linearity of Ba versus alkalinity in the ocean. Our object is to confirm the relation between Ba and Si/N ratio in the western Indian Ocean.

Seawater samples were collected at all hydrocast stations and were immediately filtrated, following the GEOTACES sampling method. They were stored into 100 ml polypropylene bottles, and were kept in the low temperature laboratory thermostatted (No. 10 Lab.) at ca. 5°C.

## 2. Early diagenesis of Ba and transition metals in sediments

The objective of this study is to clear the recycle of Ba and transition metals in pore water as well as other biophile elements, nitrate, nitrite, phosphate and silicate. The following works were carried out on board.

For pore water chemistry, sediment cores were collected at ER04, ER05, ER06, ER07, ER08, ER09, ER10, ER11, ER12, ER14 and ER15 using a multiple corer. Sediment samples were immediately extruded in the glove box, flowing N<sub>2</sub> gas, after collection. Pore waters were squeezed from each extruded sediment sample by pressure filtration using a 0.45 micrometer porosity membrane filter in another glove box, flowing with N<sub>2</sub> gas. Sediment extruding and pore water extracting were performed within 48 hr in the walk-in refrigerator Lab. 10. The concentrations of nitrate, nitrite, ammonia, phosphate and silicate were determined by using an autoanalyzer on board by M. Takeuchi, T. Asatani and Y. Nakaguchi of Kinki University. A part of each pore water sample was shared to measure Se (Kinki University), and the residues were stored in polypropylene tubes for Ba (no pre-treatment) and transition metals (acidified with 6 M HCl) analysis. And also, we will be estimated benthic flux of each element from these results of analysis.

The concentration of biogenic Ba in sediment particles will be measured, as well as carbonate and opal. The downcore distributions of these biogenic constituents give us the background information to interpret those of the pore water constituents.

## 3. Paleoceanographic study

It is generally known that siliceous phytoplankton is an abundant species in eutrophic polar waters. Oppositely in oligotrophic waters of sub-tropical to temperate regions, where the vertical mixing of surface waters is limited, calcareous plankton like coccolithophores and foraminifera are predominant. Consequently, the change of the predominant plankton species implies the variation of the trophic level of the surface water, and this suggests whether or not eutrophic waters in the tropical regions were reinforced with the climate change during the last glacial age.

For this study, long sediment cores were obtained at 2 stations using a piston corer. The ER04PC core was obtained from Arabian Sea in the tropical region, and the ER15PC from the Antarctic Ocean located in the eutrophic polar region. The downcore distributions of barite crystal, biogenic Ba, carbonate and opal will be examined, and the concentrations of metals, Fe, Mn, Al, etc., in sediments will be also determined.

## 9. Studies on sediment samples

## 9.1. Piston Core Works (Group Report)

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Masafumi Murayama; Center for Advanced Marine Core Research, Kochi University

Hideki Minami; School of Biological Science and Engineering, Tokai University (Hokkaido)

Yukako Yamada ; School of Biological Science and Engineering, Tokai University  
(Hokkaido)

Midori Sakamoto; School of Marine Science and Technology, Tokai University

Katsunori Toyomura; Graduate School of Integrated Arts and Science, Kochi University

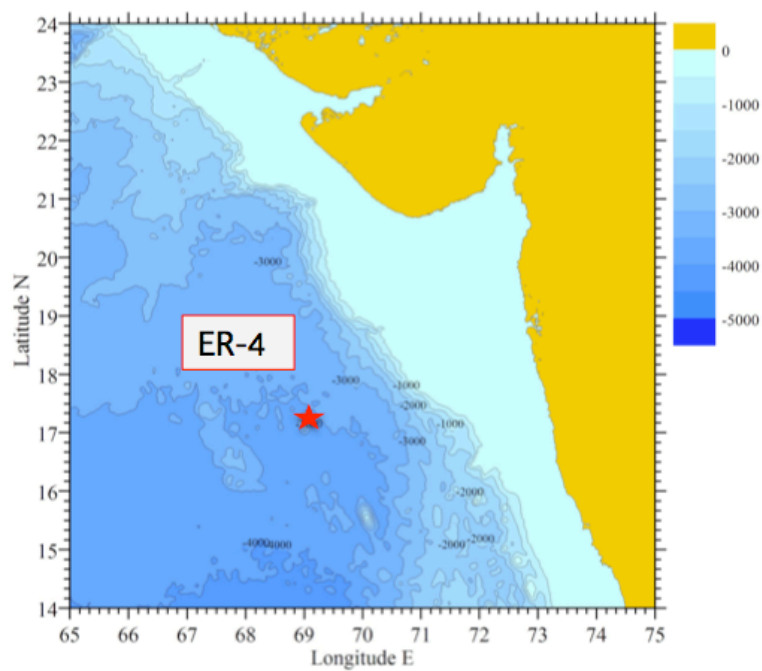
Tetsuhiro Sakamoto; Graduate School of Integrated Arts and Science, Kochi University

Sediments which provide the most complete record of past and modern oceans, play an important role in the global carbon and biogeochemical cycles. Our knowledge of the circulation and chemistry of the past ocean is based in part on the isotopic and geochemical studies of sediment. Therefore, it is important to understand the sources and the processes, which control the materials in the bottom sediments.

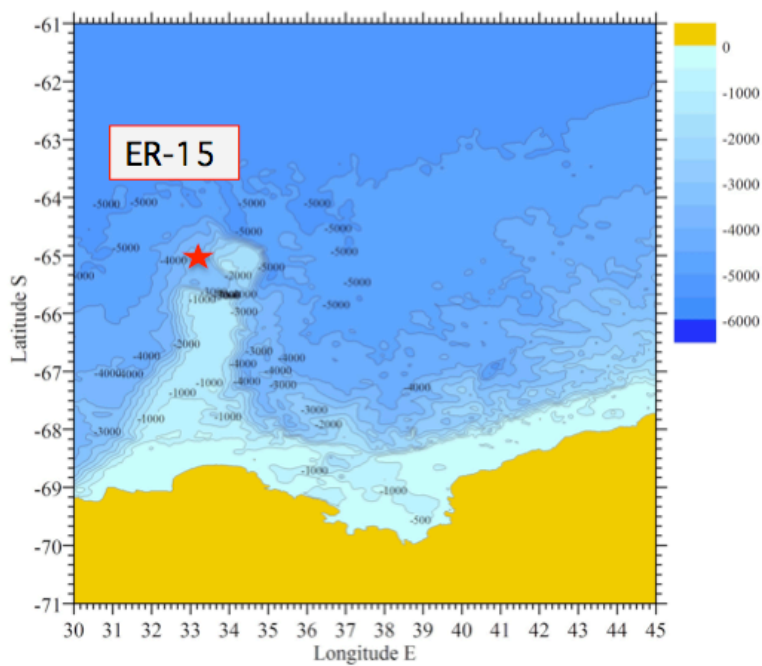
Our main objective of the core group is to treat the biogeochemical change of ocean fluxes systems in the Indian Ocean during glacial-interglacial cycles. To resolve this objective, we collected long sediment cores at 2 stations in the Arabian Sea and the Southern Ocean using a piston corer (Fig.1, Fig.2). The coring sites were decided by surveying the sea floor topography using a 3.5 KHz sub-bottom profiler, where were topographically flat and existed by stratigraphical thick sediments. The piston corer used on board is composed of 900 kg weight and 15 m length aluminum pipe.

The sediment cores obtained at each site were presumably carbonaceous, and those lengths were ca. 14.2 m at ER-4, and 14.7 m at ER-15 respectively. On board, we cut sediments in each 1 m-length pipe and stored in Lab. 10 (about 4 °C). These samples will be transported to Center for Advanced Marine Core Research, Kochi University and will be preserved in the core repository.

In the shore-based research, we intend to measure useful parameters to clear the paleoceanography of in the Indian Ocean, as follows; (1) climatic change of paleoceanography in the Arabian Sea and the Southern Ocean, (2) assemblage analysis of calcareous microfossils to estimate the age of the sediment, (3) oxygen isotopes (O-18/O-16 ratio) and radio isotopes (Th-230, Th-232 and C-14) to determine the sedimentation rate, (4) biogenic materials (organic carbon, barite, CaCO<sub>3</sub> and SiO<sub>2</sub>), lithogenic elements (Al, Ba, Ti, Fe, Mn, U, etc.) and organic compounds (UK-37, stable isotopes of C and N, lipids and pigments) to reconstruct past changes in oceanic mass fluxes.



**Fig. 1. Topographic Map in ER-04.**  
 (Data from ETOPO1)  
 Hit the bottom Data  
 2009/11/29 17-17.06°N, 69-03.41°E;  
 Water Depth 3,498 m (3.5KHz)



**Fig. 2. Topographic Map in ER-15.**  
 (Data from ETOPO1)  
 Hit the bottom data  
 2010/01/01 65-00.74°S, 33-19.67°E;  
 Water Depth 3,253 m (3.5KHz)

## Multiple Core Works (Group Report)

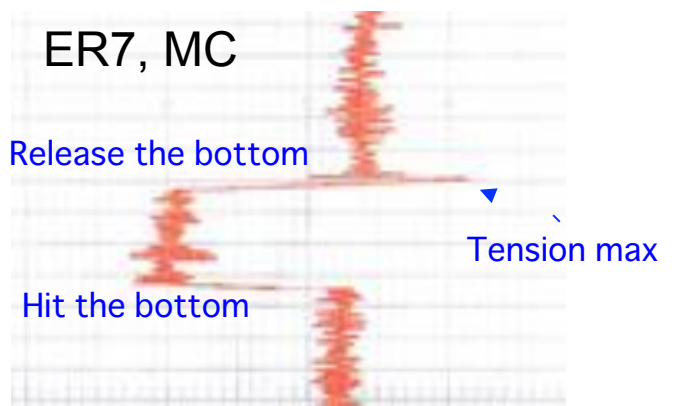
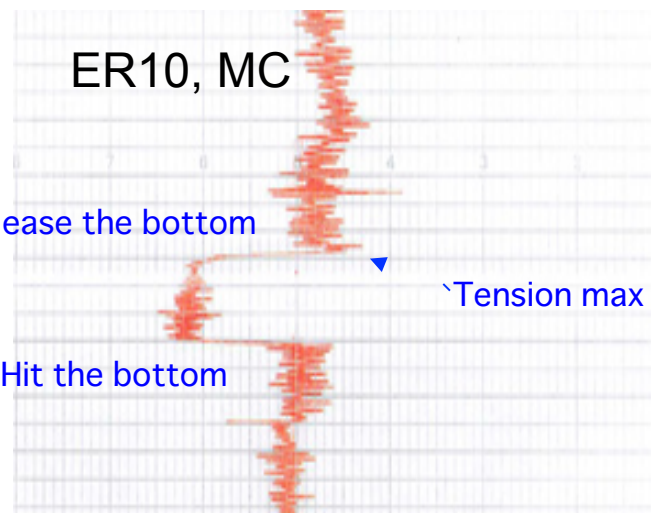
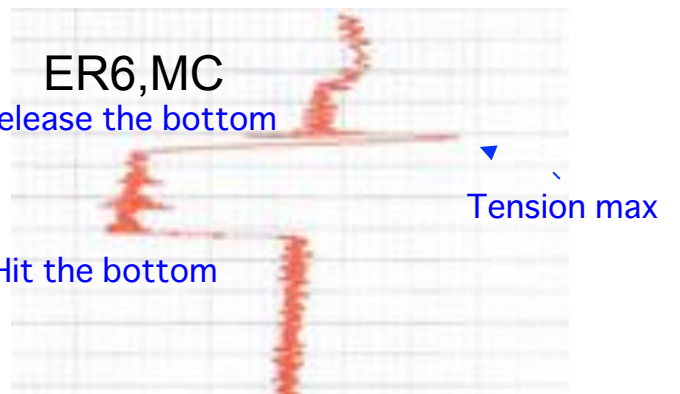
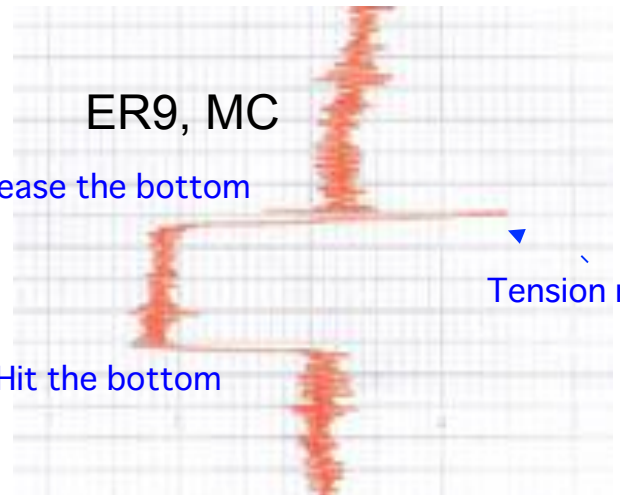
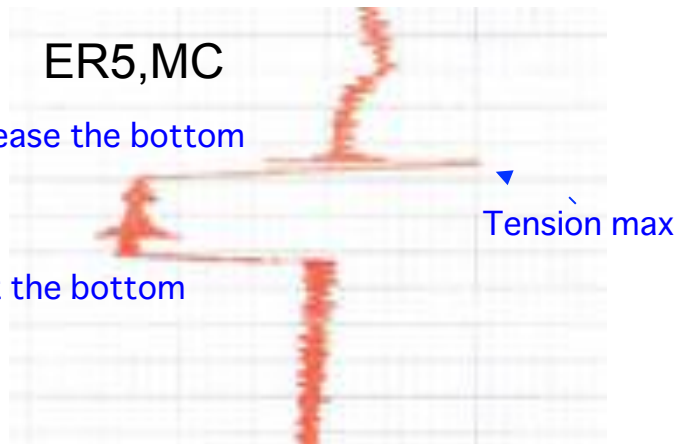
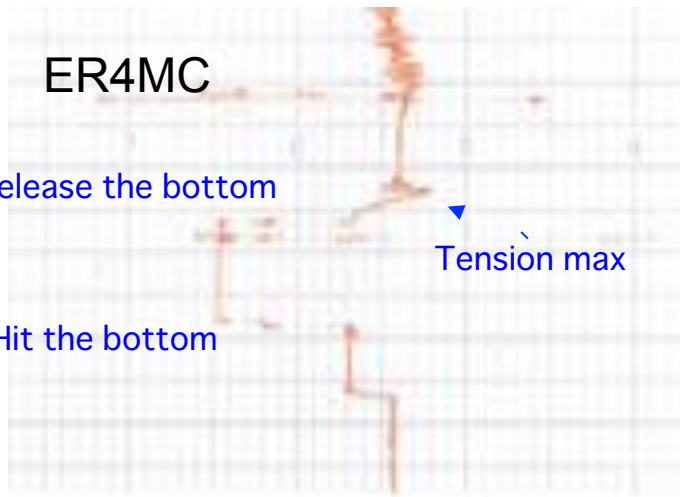
Surface cores were collected at 11 stations along a longitudinal section in the Indian Ocean (ER-4 to ER-15, except ER-13) during Leg 2 and 3 (Table. 1).

The samples were recovered by a multiple-corer fitted with eight 60 cm polycarbonate core tubes with 8 cm diameter. Core samples were once reserved in a cold room (about 4 °C) immediately after recovery, and were treated for several research objectives (Table 2).

Table.1 Location, depth and recovery of multiple and piston cores sampling.									
	Date	Site	Corer	Latitude	Longitude	Depth (m)	W. O. (m)	Recovery(cm)	Characters
Leg.2	29.Nov.09	ER-04	MC	N 17°16.87'	E 69°03.71'	3,500	3,498	27	calcareous clay
			PC	N 17°17.06'	E 69°03.41'	3,498	3,478	1,420	calcareous clay
	30.Nov.09	ER-05	MC	N 16°45.02'	E 69°00.03'	3,626	3,648	21	calcareous clay
	1.Dec.09	ER-06	MC	N 14°00.01'	E 68°58.96'	4,090	4,113	22	silty clay
	3.Dec.09	ER-07	MC	N 10°00.03'	E 68°45.03'	4,510	4,538	29.5	red clay
	5.Dec.09	ER-08	MC	N 03°59.99'	E 69°00.73'	4,162	4,071	25	calcareous clay
	7.Dec.09	ER-09	MC	S 05°15.99'	E 67°54.53'	3,316	3,332	23	calcareous ooze
	12.Dec.09	ER-10	MC	S 19°59.77'	E 72°32.83'	4,338	3,332	32	silty clay
	21.Dec.09	ER-11	MC	S 30°00.00'	E 64°59.90'	4,707	4,723	37	red clay
	25.Dec.09	ER-12	MC	S 37°45.87'	E 57°37.86'	5,401	5,440	30	silty clay
Leg.3	31.Dec.09	ER-14	MC	S 62°00.00'	E 40°05.00'	5,187	5,226	32	siliceous clay
	1.Jan.10	ER-15	MC	S 65°00.59'	E 33°19.87'	3,250	3,257	31	siliceous clay
			PC	S 65°00.74'	E 33°19.67'	3,253	3,235	1,470	siliceous clay

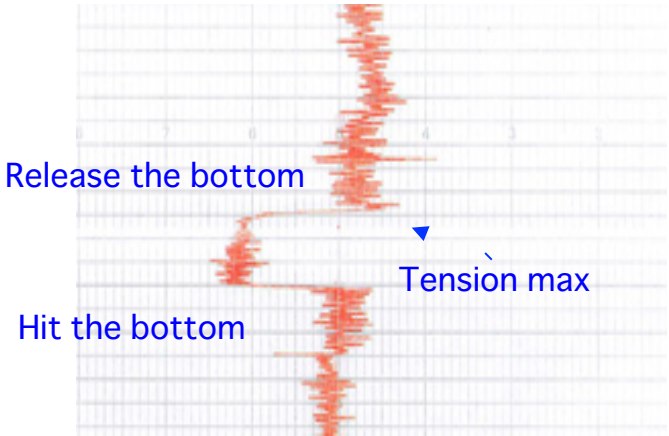
**Table 2 Distribution of multiple core and objectives.**

	Affiliation	Name	Objective
1	O.R.I	Shirai	He
2	The univ. of Tokyo	Matsuzaki	<sup>129</sup> I
3	Tokai Univ.	Kato	metals
4	Tokai Univ.	Minami	pore water
5	AIST	Yamashita	PFOS
6	Nihon Univ./O.R.I.	Tazoe/ Kim	<sup>10</sup> Be/Th, Pa
7	Kochi Univ.	Murayama	chronology
8	Kochi Univ.	Murayama	description

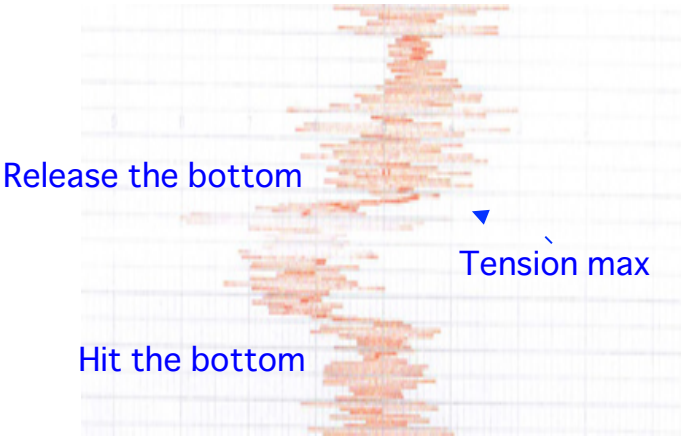




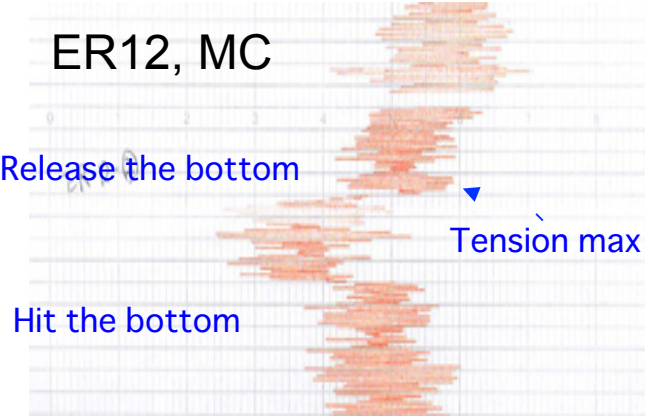
ER11, MC



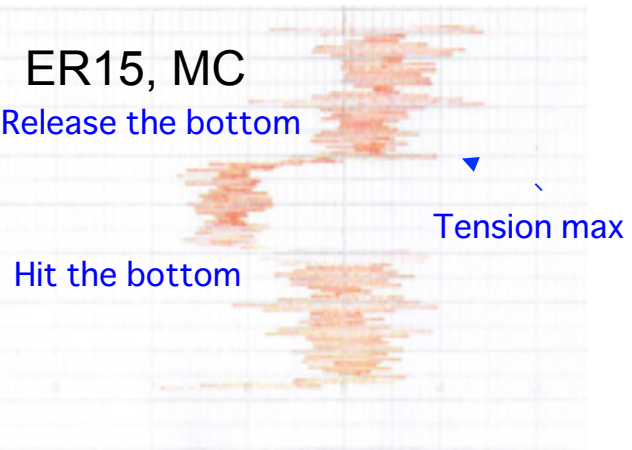
ER14, MC



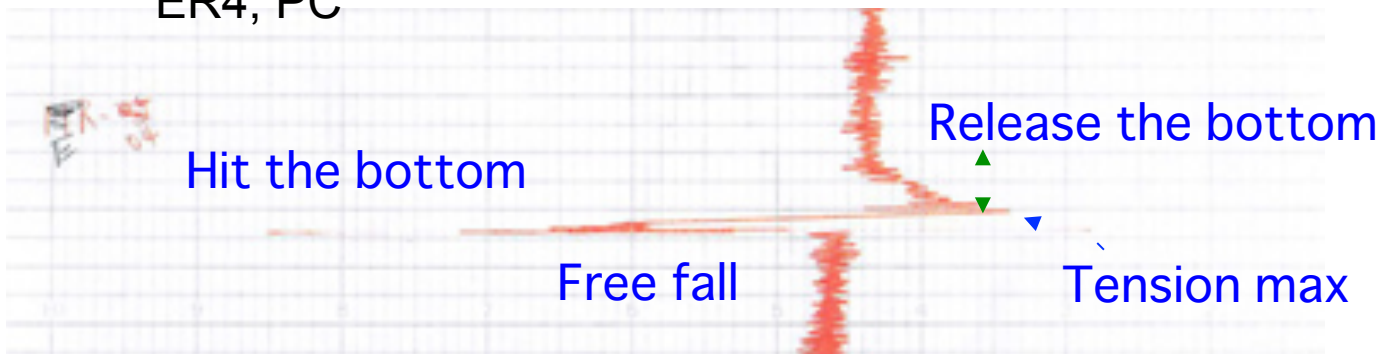
ER12, MC



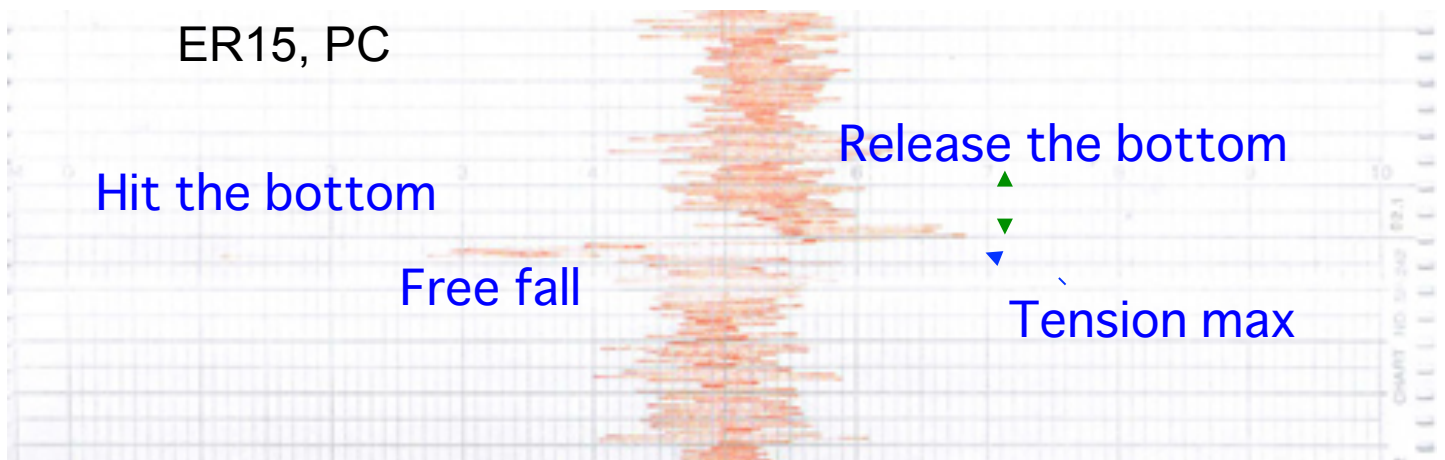
ER15, MC



ER4, PC



ER15, PC



### **9.3. Distribution and its characteristics of surface sediment in the Indian Ocean**

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Katsunori Toyomura, Tetsuhiro Sakamoto

Graduate School of Integrated Arts and Science, Kochi University

Surface sediment cores were taken from the 11 stations along a longitudinal section in the Indian Ocean using a multiple corer during this cruise (table list in this report). Our objectives are to survey the distribution of sediments varying depth preferences, to determine the components and age of sediments and to reconstruct their stratigraphic histories, as indicators of the paleoceanographic events during the late Quaternary.

#### ***Sampling and Methods***

2 cores at each site were used. During on-board works, a core was used for visual description, taking close-up photographs, color analyses using a digital color photospectrometer (MINOLTA CM-2022) and measuring magnetic susceptibility (Bartington). The other core was sectioned at 1 cm intervals for oxygen isotope chronology, AMS-<sup>14</sup>C dating and micropaleontological assemblage assessment.

Shore-based operations will include non-destructive physical determinations using a X-ray CT Scanner and a Multi-Sensor Core Logger (MSCL). MSCL will be used to determine the values of various physical properties (gamma density, p-wave, magnetic susceptibility, digital color image, electric conductivity, natural gamma ray). Following this, the sediments cut into segments with 1 cm thickness for grain size analysis and composition of minerals to evaluate the source of sediments during the environmental changes in the past.

## 9.4. Helium isotopes of pore-water in open ocean sediments

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Center for Advanced Marine Research, Ocean Research Institute, the University of  
Tokyo

### **Purpose**

Helium-3 is the most important parameter of mantle-derived materials and its flux may provide constraints on the source of terrestrial heat flow as well as the mass balance of atmospheric helium. However the direct observation of the helium-3 flux in the ocean floor is not well documented in a literature. We present here the flux estimated by vertical profiles of  $^3\text{He}/^{20}\text{Ne}$  ratios of pore water samples in deep sea sediments.

### **Sampling method**

We have collected surface sediment samples by using a standard eight-tubes multiple-corer. Two thick wall acrylic tubes (62 cm length and 10.5 cm external diameter) were set in the corer. There were five holes drilled in the tube wall, which were pre-tapped with 1/4" NPT plugs. When the multiple-corer was recovered onboard, the both ends of the tube were immediately closed by two PVC pistons. Then the tube with a sediment sample was set into a whole core squeezer (Bender et al., 1987). First, the lower-most NPT plug was removed and a standard copper tube container (1/4" diameter with 30 cm long) was connected using a tube fitting. Second, the soft sediment in the tube was squeezed by the machine and it was transferred without exposure to atmosphere into the copper tube. Third, the both ends of the copper tube were sealed by using stainless steel clamps for storage. After the lower-most sample was finished, the second one close to the first was processed. Experimental details are given elsewhere (Pitre et al., 2009).

### **On land experiments**

The copper container with a pore water sample is connected to a stainless steel high vacuum line and dissolved gases are extracted from the sample in vacuo. He and Ne in the exsolved gas are purified using hot titanium getters and charcoal traps at liquid nitrogen temperature. The  $^4\text{He}/^{20}\text{Ne}$  ratio is measured by an on-line quadrupole mass spectrometer. He is then separated from Ne using a cryogenic trap held at 40 K. The  $^3\text{He}/^4\text{He}$  ratio is measured on a conventional noble gas mass spectrometer (VG5400, MicroMass Co.).



## Appendices:



A group photo during the leg-2



A group photo at the end of the leg-3 (Port of Cape Town)