SN-51 Southern Ocean Expedition 2011

Cruise report

24th January to 10th March 2011

Preface

The fifth Expedition to the Indian sector of Southern Ocean was commenced onboard Oceanographic research vessel TDV Sagar Nidhi on 24th January 2011 at 2100 hrs IST from Port Luis, Mauritius. . This cruise was conducted mainly to collect multi-disciplinary data and samples from the Subtropical to Polar Regions of the Indian sector of the Southern Ocean [SO]. A team of 17 scientists from NCAOR, Goa; Central Institute of Fisheries Technology, Kochi; Central Marine Fisheries Research Institute, Kochi; Federal University of Rio Grande, Brazil; Jawaharlal Nehru University (JNU), New Delhi; Indian Institute of Sciences (IISC), Bangalore; Birla Institute of Technology (BIT), Mesra, Ranchi; Goa University and three engineers from NORINCO Pvt. Ltd. (Norway India Collaboration), Chennai participated in this cruise.

Continuous underway observations were made for ocean currents, atmospheric parameters and bathymetric data by operating the instruments such as Acoustic Doppler Current Profiler, Automatic Weather Station, Multi-beam, Echo-sounder and Sub-bottom profiler were operated. The observations started from 37°00'S 57°30'E and two meridional sections along 57°30'E and 47°00'E were covered during this expedition. Measurements were carried out along one zonal section also from 60°S 57°30'E to 60°S 47°00'E. In the Subtropical (42°00'S 47°00'E) and the Polar Regions (51°30'S 57°30'E) two time series observations were carried out for a period of three days. During these observations CTD was operated at three hourly intervals however MPN and Bongo net measurements were made at six hourly intervals to see the changes of nutrients and microorganisms with time, temperature and light penetration. From the outside EEZ (Exclusive Economic Zone) of Mauritius all metrological observations and sea surface data collections were made at three hourly intervals in the entire cruise track from 30th January to 4th March 2011. Observations at all zones and fronts namely Subtropical, Polar and Sub-Antarctic (based on the drastic variations in hydrographic parameters) were covered during this expedition. At 43°00’S 57°30’E and 52°00’S 47°00’E operations could not be carried out due to bad weather and high sea state conditions. According to the requirement mostly in each station one shallow cast (upto 100 meter sample depth) and one deep cast (upto near bottom sample depth) were performed. In the entire cruise track the depth of the ocean was varying between 5900m and 100m depends on the bottom topography due to Southwest Indian ridge and Crozet plateau. At the shallower depth of three different places grab sampling and corer operations were carried out to collect the bottom sediments. 115 XCTDs were launched out of which 95 numbers of profiles were collected in the entire cruise track between 27°00’S 57°50’E and 30°00’S 47°00’E at 30 miles to one degree latitudinal intervals for salinity and temperature profiles.

The atmospheric and oceanographic observations made in the Indian sector of Southern Ocean region during the austral summer 2011 shall help to enlightening our scientific understandings about the biogeochemistry, hydrodynamics and air-sea interaction process occurring in the Southern Ocean. The data and sample collection during SOE-2011 are satisfactory considering the scientific objectives of the expedition although there were problems due to bad weather and high sea states. The remarkable efforts made by the expedition members for data collection even in the bad weather/rough sea conditions are highly appreciated.

ACKNOWLEDGEMENTS

We the scientific team of SN-51 onboard Sagar Nidhi are grateful to Dr. Shailesh Naik the Secretary, Ministry of Earth Sciences for the immense help provided by him for the successful execution of this Southern Ocean Expedition programme. We are thankful to Shri Rasik Ravindra Director NCAOR for his constant support and enormous help for the successful implementation of this expedition. We thankfully acknowledge Dr. Atmanand Director NIOT and Dr. Rajasekhar, Head, Vessel Management Cell, NIOT and all other staff in VMC for all arrangements made by them onboard Sagar Nidhi for this expedition. We thank the Captain, all ABS Officers and crewmembers onboard Sagar Nidhi for the proper navigation of the vessel which helped us in collecting the required samples and data at the preplanned station locations along the cruise track. We are thankful to the catering officer and all his staff for serving us tasty and homely food. We thank NORINCO engineers for the service provided by them in operating all the required scientific equipments onboard during this cruise. The Mauritius Indian High Commission, all staff of NCAOR who contributed to the successful implementation of this expedition are respectfully acknowledged.

[N. ANILKUMAR]

CHIEF SCIENTIST

CONTENTS

1. Introduction

Southern Ocean (SO), encircling the Antarctica starts from subtropical frontal region around 35°S. SO plays a crucial role in regulating the global ocean atmospheric climate system. The Antarctic land mass covered by glaciers is the source of fresh water to the SO. Surface winds have a significant role in the mixing and dynamics of the SO. Wind driven currents and fronts in SO aids in the formation of latitudinaly separated zones with distinct physical and biological features. As compared to other oceanic regions SO is the least investigated region. Presence of ice and challenging climatic conditions make scientific measurements difficult here. Moreover, Indian Ocean sector of SO is a data sparse region.

As part of the ongoing efforts to broaden our understanding of Indian Ocean sector of SO, the fifth Indian Scientific Expedition to SO was launched in January, 2011. The scientific team set sail from Port Luis, Mauritius onboard ORV *Sagar Nidhi* on 24th January, 2011. The team comprised of 15 scientists from various national institutes and universities. Two scientists from Federal University of Rio Grande (FURG, Brazil) also participated in the expedition.

Major operations carried out during the expedition were (i) Profiling of water column using CTD and collection of water samples with attached rosette system up to 5300 m depth (ii) Multiple plankton net sampling of zooplankton (iii) Bongo net deployment for collecting surface zooplankton (iv) Firing of XCTDs to delineate the vertical structure of water column in high resolution (v) Grab corer for sea bottom surface sampling (vi) Continuous observations of atmospheric surface layer parameters using automatic weather station (AWS). Time series observation of physical, chemical and biological parameters from two different frontal regions was a major accomplishment of this year's expedition. The data generated during this expedition may throw more light into several intriguing aspects of the SO system.

2. Objectives

The agenda for research in the Southern Ocean realm underlines the sensitivity of the Southern Ocean region to climatic variability and its importance in understanding the climate at large. The Southern Ocean research plan mainly focuses on:

"Role and response of Southern Ocean to the regional and global climate variability"

Towards achieving this the following objectives have been identified:-

- To study the inter relationship between physical, chemical and biological elements occurring across the Antarctic Circumpolar Current (ACC) and their role in carbon sequestration, biogeochemistry and climate change.
- To investigate the air-sea-ice interaction and to understand the role of anthropogenic aerosols over southern ocean and its effect on climate variability.
- To understand the implication of thermohaline variations in the Southern Ocean and the repercussion of heat and mass exchange between tropics and Polar Regions on Indian monsoon, biogeochemistry and climate.
- Reconstruction of the paleo-environmental conditions for selected time slices during the last glacial-interglacial cycles to provide perspectives on future climate change.
- To generate relevant/critical sea truth and atmospheric data for contributing to global climate data sets for prediction of climate models to mitigate/regulate climate change.

Within the frame work of the above mentioned major focal themes, studies were conducted to investigate the following objectives:

1. **1.** Investigation of marine atmospheric surface layer and its dynamics.
2. **2.** Understanding the diurnal variations of physical properties and their impact on chlorophyll concentrations in the major frontal regions.
3. **3.** Study the mechanism of maintenance of deep chlorophyll maximum in the frontal

regions.

4. Influence of mixed layer dynamics, Ekman dynamics, euphotic zone variations and eddies on the chlorophyll distribution.

5. Monitoring the changes in the oceanic thermohaline structure along two meridional repeat hydrographic sections.

6. Understanding the heat content and heat and mass transport in the study region.

7. Identifying water masses using stable isotopes (^{18}O).

8. Identify the relationship between oceanographic parameters and deep sea mega fauna and marine mammals.

9. Investigation of the source, distribution, components and chemistry of suspended particulate matter.

10. Measuring the inherent bio-optical properties of SO waters.

11. Deriving quantitative information on the types of substances (*e.g.* chlorophyll concentration, suspended matter, yellow substances, and attenuation coefficient) present in the water and their concentrations, based on spectral variations.

12. Isolation and molecular characterization of novel microalgal species from SO towards exploring their metabolic potential and biological variability.

13. Study the composition of phytoplankton communities in the region, using the photosynthetic pigments as taxonomical biomarkers.

14. To determine possible relationship between phytoplankton communities (through pigment composition) and the ACC fronts zones.

15. Diurnal variability in planktonic standing stock and diversity in the two major fronts (Polar front and subtropical front)

3. Participating Organizations and Participants

1. **National Centre for Antarctic and Ocean Research, Goa**
    1. Dr. N. Anilkumar (Chief Scientist)
    2. Mr. Denny P. Alappattu
    3. Ms. Racheal Chacko
    4. Dr. Mrs. Sini Pavithran
    5. Dr. Mrs. Deepti Dessai
    6. Mr. Jenson V. George
    7. Mrs. Honey U. K. Pillai
2. **Goa University, Goa**
    8. Ms. Cheryl Arcanjela Noronha
3. **Centre Institute Fisheries Technology, Kochi**
    9. Mr. Shaju S. S.
4. **Central Marine Fisheries Research Institute, Kochi**
    10. Dr. R. Jeyabaskaran (Dy. Chief Scientist)
5. **Birla Institute of Technology, Ranchi, Jharkhand**
    11. Dr. Rajib Bandopadhyay
    12. Dr. Pratyoosh Shukla
6. **Jawaharlal Nehru University, New Delhi**
    13. Mr. Alok Kumar
7. **Institute of Oceanography, FURG, Brazil**
    14. Ms. Camila Burigo Marin
    15. Ms. Amalia Maria Sacilotto Detomi
8. **Indian Institute of Science, Bangalore**
    16. Mr. N. Prasanna Kannan
9. **National Institute Ocean Technology, Chennai**
    17. Mr. D. Narendra Kumar
    18. Mr. Vinod

Apart from the above participants, three engineers from NORINCO as well as officers and crew of the vessel also actively participated in conducting various operations onboard.

4. Cruise Itinerary

Departure from Port Louis, Mauritius: 24th January 2011

Arrival at Port Louis, Mauritius: 10th March 2011

5. Equipments Used/Operated

1. Expendable Conductivity Temperature Depth (XCTD)
2. Conductivity Temperature Depth (CTD)
3. Niskin bottles
4. CTD winch
5. Gravity corer
6. Bucket thermometer for Sea Surface Temperature (SST)
7. Titration- Dosimat unit
8. Vessel Mounted Acoustic Doppler Current Profiler (VMADCP)
9. Vaisala Automatic Weather Station (AWS)
10. pH meter
11. Auto analyzer
12. Total Dissolved Solid (TDS) meter
13. Spectrophotometer
14. Spade corer
15. Bongo net
16. Multi-Plankton Net (MPN)
17. Milli-Q water purifier
18. Kongsberg multibeam
19. Sub-bottom profiler
20. Oven

6. Data Statistics

6.1 Atmospheric Sciences

6.1.1 Atmospheric and Oceanic CO_2 Budget **(IISc., Bangalore)**

The budget and chemistry of atmospheric CO_2 are controlled by its concentration. However, the most significant sources and sinks of CO_2 (photosynthesis, respiration, anthropogenic emissions, dissolution in and exsolution from the oceans) vary in flux and isotope signature and hence the atmospheric budget cannot be defined by inversion of isotopes and concentration alone. Study of multiply substituted isotopologues can be used as additional constraint in determining the overall budget and in understanding the mechanisms of CO_2 production and consumption in model systems. Clumped isotope geochemistry is an area of study which is concerned with the state of ordering of rare isotopes in natural materials.

In reporting data for abundances of mass $\Delta47$ CO_2, variable $\Delta47$ is defined as the difference in per mil between the measured value of ratios of mass 47 to mass 44 and the value of ratios of mass 47 to mass 44 expected in that sample if its stable C and O isotopes are randomly distributed among all isotopologues a case referred to as the stochastic distribution. It has been considered that CO_2-water exchange is overwhelmingly dominated by leaves in the northern hemisphere of the globe, whereas air-sea exchange is proportionately more important in the southern hemisphere. There is no direct information on the $\Delta47$ of CO_2 out-gassed from the ocean. However, if it reflects thermodynamic equilibrium of CO_2, $\Delta47$ should be higher in the south than the north for a given temperature of exchange. If instead, $\Delta47$ of out-gassed CO_2 reflects thermodynamic equilibrium of dissolved carbonate species values, it could be lower in the south than in the north.

Methods

Air samples were collected in three litre glass flasks using indigenously designed battery operated air sampler with moisture trap. Suitable flushing time was provided before the air samples were collected. Samples were collected at high pressure with minimum pressure at 0.9 Kg/cm^2 and maximum pressure of 1.2 Kg/cm^2. Care was taken to ensure no breath or engine exhaust contamination occurred to the samples during collection.

CO_2 from the glass flasks was extracted using cryogenic separation techniques. The measurement of stable isotope composition of CO_2, including mass 47, was done using a high precision MAT 253 isotope ratio mass spectrometer configured to measure ion beams corresponding to M/z = 44 through 49, inclusive.

Air samples were taken at the following locations along with surface water to understand the isotopic equilibration exchange (Table 1). Ocean water samples at 0 m, 50 m and 120 m were taken to understand the change in salinity and nutrients. Samples at 0 m were sealed in air tight containers for analysis of dissolved CO_2 and isotope analysis.

Table 1: Locations of sample

Air samples				
Sample number	Latitude (S)		Longitude (E)	
	Deg	Mins	Deg	Mins
1	38	08	57	30
2	40	07	57	29
3	44	59	57	30
4	50	00	57	30
5	52	00	57	30
6	54	01	57	30
7	60	02	51	59
8	60	03	48	33
9	60	04	48	33
10	58	06	46	53
11	56	00	47	00
12	46	23	47	00
13	43	59	46	59
14	41	59	47	00
Water Samples				
Sample number	**Latitude (S)**		**Longitude (E)**	
	Deg	**Mins**	**Deg**	**Mins**
1	37	00	57	30
2	39	01	57	30
3	41	02	57	30
4	45	03	57	30
5	48	04	57	30
6	50	05	57	30
7	52	06	57	30
8	54	07	57	30
9	56	08	57	30
10	58	09	57	30
11	60	10	57	30
12	60	11	55	00
13	60	12	53	00
14	60	13	51	00
15	60	14	49	00
16	60	15	47	00
17	58	16	47	00
18	56	17	47	00
19	54	18	47	00
20	52	19	47	00
21	50	20	47	00
22	48	21	47	00
23	46	22	47	00
24	44	23	47	00
25	42	24	47	00

6.1.2 Air Sea Interaction fluxes **(NCAOR, Goa)**

Investigation of marine atmospheric surface layer and its dynamics, which governs ocean–atmosphere interaction, is imperative for coupled ocean–atmosphere modeling and numerical weather prediction. Moreover, atmospheric momentum flux drives the ocean currents and ocean surface mixing, and thereby determines wave formation over the ocean surface. It is also understood that the momentum flux along with surface energy and fresh water fluxes control the sea surface temperature. However, the open ocean measurements of surface layer turbulent fluxes are generally difficult due to unavailability of a stable platform over the oceanic surface.

The SO surrounding the Antarctic continent plays a significant role in the global climate system. The Antarctic land mass covered by the glaciers is the source of fresh water to the SO. Surface winds have a significant role in the mixing and dynamics of the SO. Wind driven currents and fronts in SO aids in the formation of latitudinaly separated zones with distinct physical and biological features. Compared to the corresponding northern latitudes, SO is devoid of land mass and this in turn results in the high surface wind speeds. The higher amount of the vertical transfer of the momentum from the horizontal winds leads to deeper oceanic mixed layers over in SO.

Investigation of air sea interaction fluxes is imperative for understanding the coupling between oceanic mixed layer and atmospheric surface layer. *Insitu* measurements of these surface layer fluxes from SO are very sparse, in comparison with other regions of the world oceans. Thus 5th Indian scientific expedition to SO provided a unique opportunity for the *insitu* observations of atmospheric surface layer from this data sparse region.

Continuous measurements of surface layer parameters viz. (a) pressure, (b) air temperature, (c) sea surface temperature, (d) relative humidity, (e) rain rate, (f) short wave radiation (g) wind speed and wind direction are carried out during the cruise using an automatic weather station (Vaisala AWS). Instantaneous position of the ship was also recorded using a GPS receiver. In this report the spatio-temporal variations of some of the above mentioned parameters measured during the expedition are presented.

Figure 1 shows the cruise track of the expedition. The onward track is a transit through 57.5°E starting from 25°S to 60°S and return track is through 47°E. These two tracks are connected through a zonal track along 60°S. In Figure 2, upper panel shows the pressure variation observed during the cruise. Middle panel shows the variation of temperature and dew point temperature along the cruise track with Julian day number and lower panel is the relative humidity recorded during the expedition. Figure 3 shows the observed wind speed and wind direction during the cruise. Sea surface drag and wind stress estimated from this data set is given in the upper and lower panels of Figure 4. More detailed study of these parameters will be made to understand the role of air sea interaction fluxes in regulating the dynamics of ocean and atmosphere over this region.

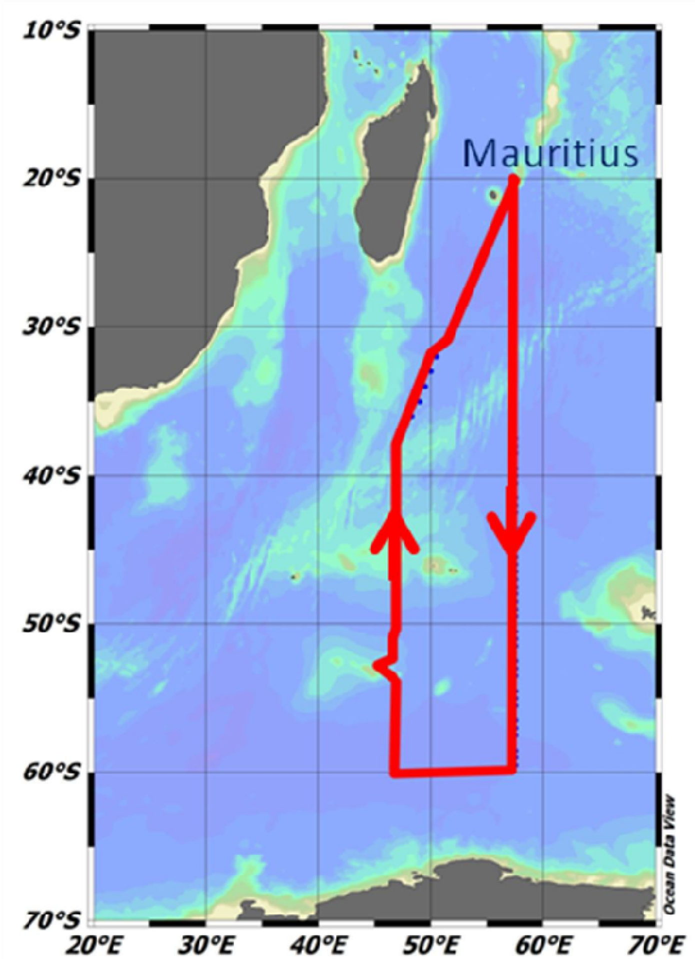


Figure 1: Cruise track of 5th Indian scientific expedition to SO

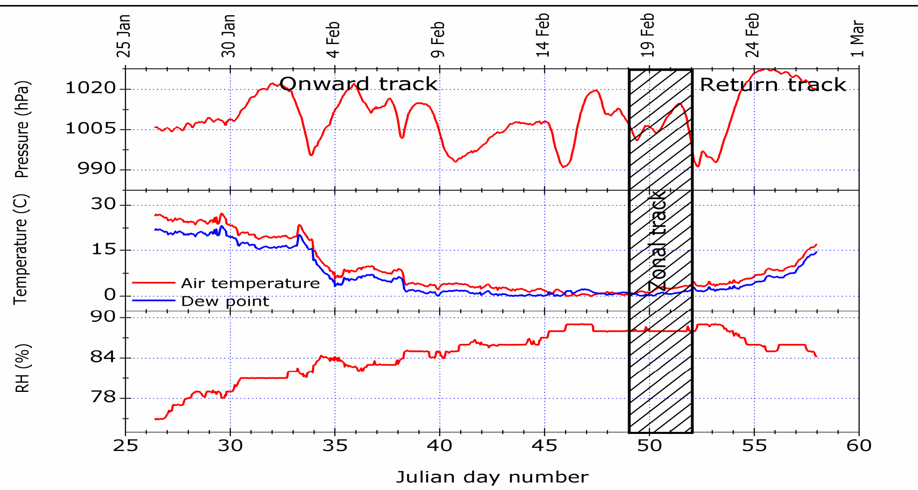


Figure 2: Spatio temporal variation of pressure (upper panel) air temperature and dew point (middle panel) and relative humidity (lower panel).

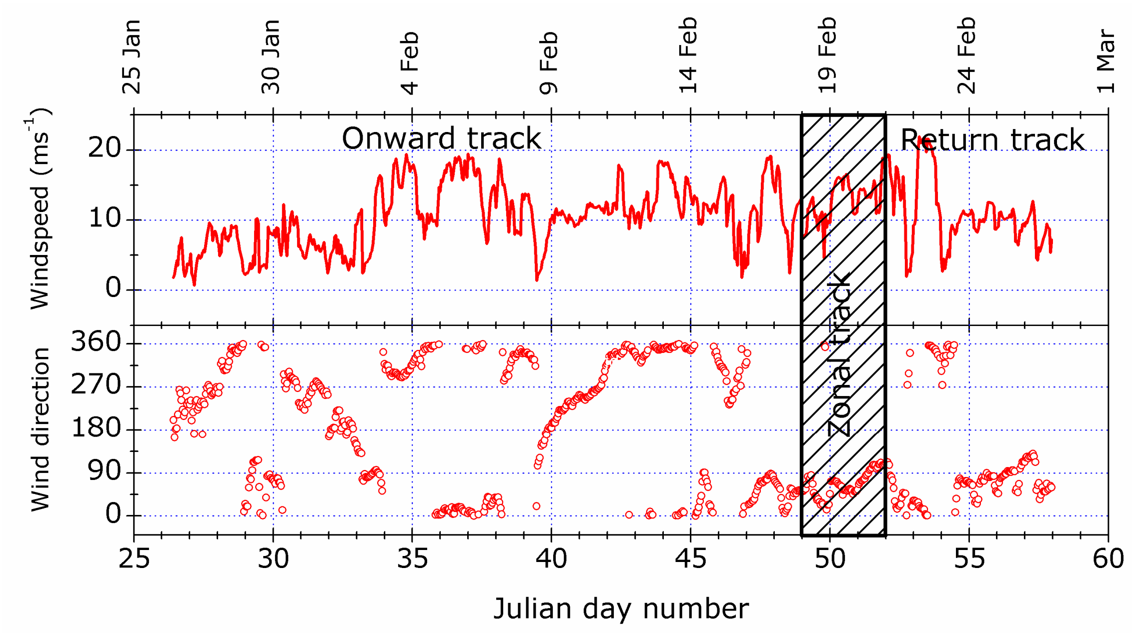


Figure 3: Spatio temporal variation of wind speed (upper panel) and wind direction (lower panel)

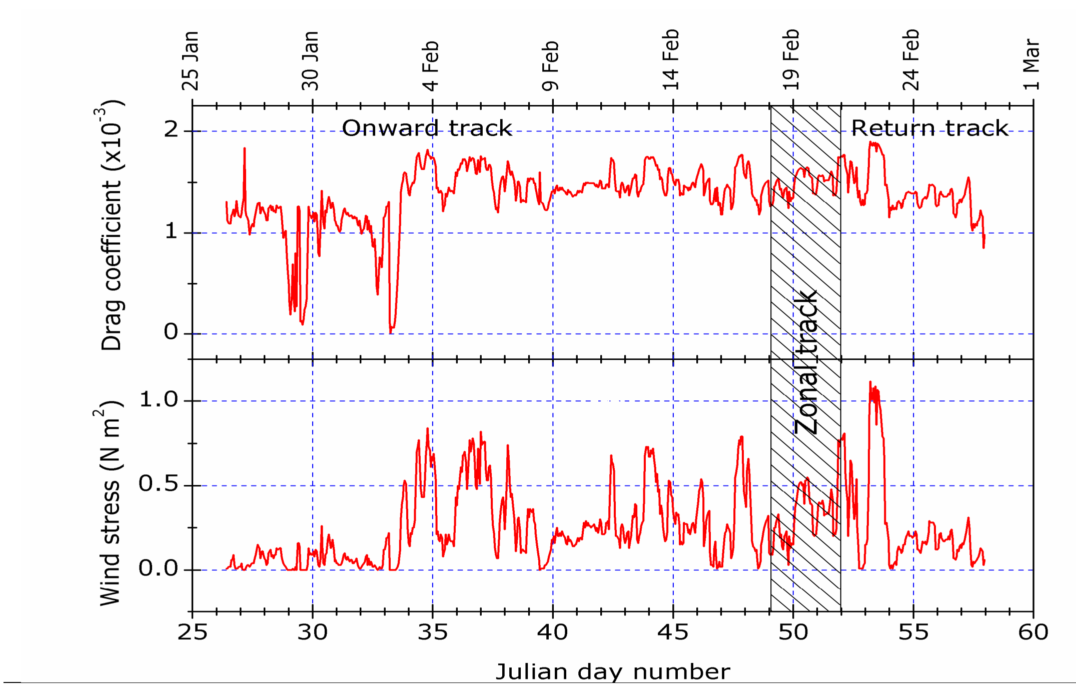


Figure 4: Spatio-temporal variation of estimated drag coefficient (upper panel) and wind stress (lower panel)

6.2 Physical oceanography (NCAOR, Goa)

Introduction

Due to its physical geography, the SO is a major pathway for exchange of water properties between ocean basins, and between the surface ocean and the deep. The Antarctic Circumpolar Current (ACC) system driven by mid-latitude surface westerly winds accounts for this large fluxes of heat, nutrients, and carbon in the climate system. At the same time, it effectively isolates the polar ocean from lower latitudes, giving rise to the coldest temperatures in the World's ocean, deep surface mixed layers, and a large area of seasonal sea ice. These physical characteristics have profound impacts on SO biogeochemical cycles and ecosystems. The strong north-south tilt of density surfaces associated with the eastward flow of the ACC exposes the deep layers of the ocean to the atmosphere at high southern latitudes. Wind and buoyancy forcing at these isopycnal outcrop transfers water between density layers, and connects the deep global ocean to the surface layers. In this way, SO controls the connection between the deep and upper layers of the global overturning circulation and thereby regulates the capacity of the ocean to store and transport heat, carbon and other properties that influence climate and global biogeochemical cycles. Sustained observations of temperature, salinity, stratification and ventilation are needed to detect changes in the overturning in response to changes in atmospheric forcing. Measuring distributions of ^{18}O which are natural tracers of oceanic water masses, add specific information to understand the mechanisms responsible for internal variability of water masses in their source region and at depths and allows monitoring the circulation far away from their source. SO is also the largest High Nutrient Low Chlorophyll (HNLC) region in the world ocean but satellite chlorophyll data reveal several regular surface phytoplankton blooms in certain areas. It is also noted that these phytoplankton blooms occur primarily in regions associated with sea ice retreat, shallow waters, area of strong upwelling and regions of high eddy kinetic energy which is mainly associated with frontal regions. The studies of SO phytoplankton dynamics mainly relied on satellite data but the knowledge about phytoplankton subsurface distribution and maintenance of Deep Chlorophyll Maximum (DCM) are less because of the sparse *insitu* observations in the SO and especially in the Indian sector. Elevated chlorophyll in the vicinity of fronts and its diurnal variations have not been clearly explained. To address these questions a three days time series observation was also carried out at two locations namely the Polar front and Subtropical front in the Indian Sector of the SO.

Objectives

Physical observations were undertaken to compliment the biological process studies in Indian Sector of SO in addition to repeating hydrographic monitoring along two meridional sections with the following objectives:

- Understand the diurnal variations of physical properties as well as the chlorophyll concentrations in the major frontal regions.
- Mechanism of maintenance of DCM in the frontal regions.
- Influence of mixed layer dynamics, Ekman dynamics, euphotic zone variations and eddies on the chlorophyll distribution.
- Monitor the changes in the oceanic thermohaline structure along two meridional repeat hydrographic sections.
- Understand the heat content and heat and mass transport in the study region.
- Identifying water masses using stable isotopes (^{18}O).

Methodology

A CTD (make SEABIRD 911 plus) with accessory sensors (Oxygen Sensor: Make: SBE 43, Biospherical PAR light sensor: Model No: QCP2300L-HP, and Flurometer

:WETLabs ECO-FL-NTU) was used to collect data at 2-degree interval along 57°30’E and 47°E longitudes (Fig. 5 & Table 2). CTD data were collected on each cast in most cases within 200 meters of the bottom. Along the 60°S zonal track the CTD was lowered upto 1000 m. Observations of the vertical structure of temperature, salinity, fluorescence, turbidity, Dissolved Oxygen and Photosynthetically Active Radiation were made over a period of 72 hours (3 hourly interval) at two time series locations, viz. Polar Front (51°30’S, 57°30’E) and Subtropical front (42°S, 47°E). Dense underway profiling of upper ocean temperature and salinity was carried out with expendable conductivity-temperature-depth probes (XCTDs) (make: Tsurumi Seiki Company Limited, Japan; type: XCTD-3; terminal depth: 1000 m; temperature/salinity accuracy: ±0.02°C/±0.03 mS cm^{-1}). The sampling was made at 30 nautical mile interval and supplemented full-depth CTD stations that were spaced at approximately 120 nautical miles. Station depths varied between 5900 to 100 m. Generally, three XCTDs were launched between CTD stations (Fig. 6 & Table 3). Along the 60°S zonal track, XCTD’s were deployed at 2 degree interval. Using the Vessel Mounted Acoustic Doppler Current profiler (Make: RDI; Velocity accuracy ±1.0% ± 0.5 cm/s), the velocity profiles of upper 1000 m along the cruise track were obtained. Water samples for stable isotopes were collected from various depths at all the CTD locations and stored in 100 ml plastic bottles with tight fitting double caps to prevent evaporation. Bottles were filled up to the brim to facilitate easy identification of any later evaporation/leakage and taped at the neck as a further precaution.

Preliminary Results

- An anomalous warming was observed in the Subtropical Front along 57°30’E (Fig.7).
- A downwelling feature was captured along 47°E in the latitudinal band from 47°30’S to 45°S (Fig. 8).
- At the time series location in the Polar Front (TS1), a prominent deep fluorescence

maximum was present with fluorescence values greater than 1 $mg.m^{-3}$ at depth around 75 m. The surface fluorescence values ranged between 0 and 1 mg. m^{-3} (Fig. 9).

- At the time series location in the Sub Tropical Front (TS2), high variability in deep fluorescence maximum was observed with depth varying from near-surface to 50 m and values varying between 0.4 and 1 $mg.m^{-3}$. Fluorescence values between 0 and 0.7 $mg.m^{-3}$ was observed in the surface waters (Fig. 10).

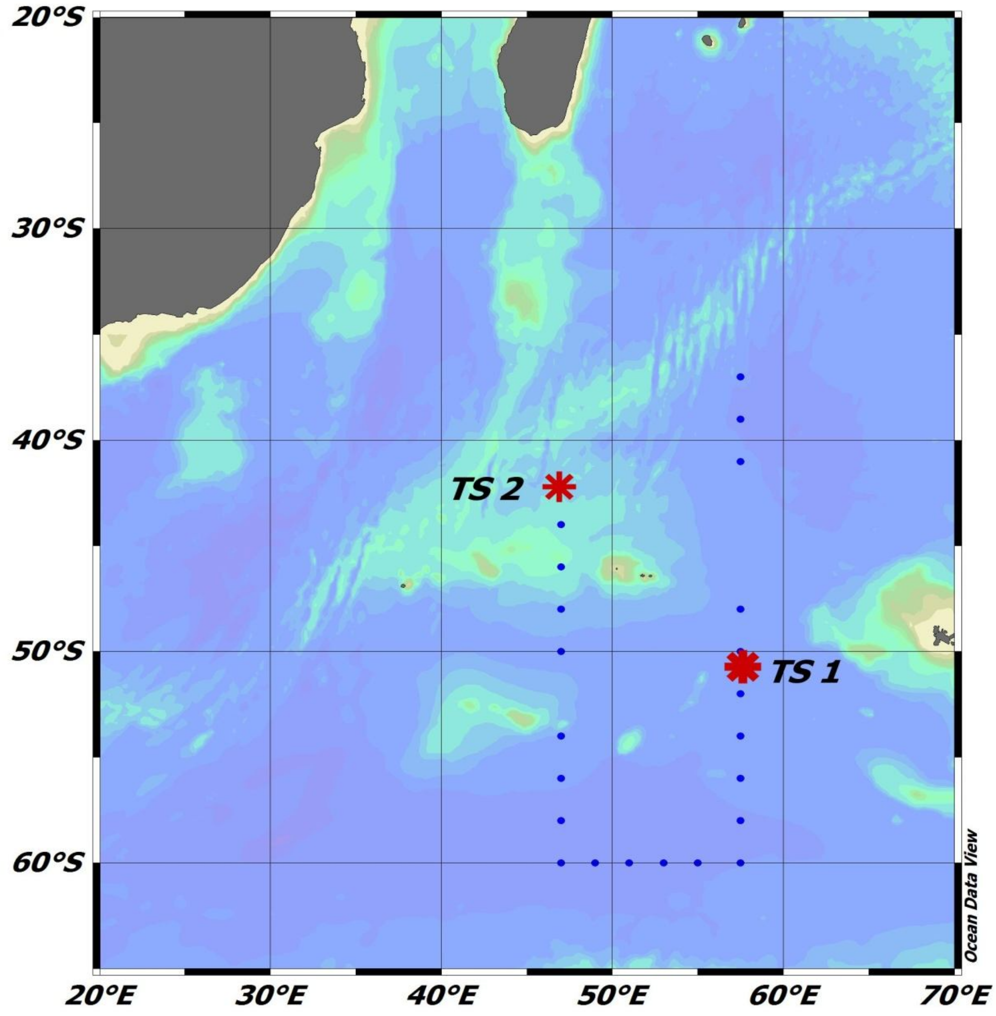


Figure 5: CTD and Time series location

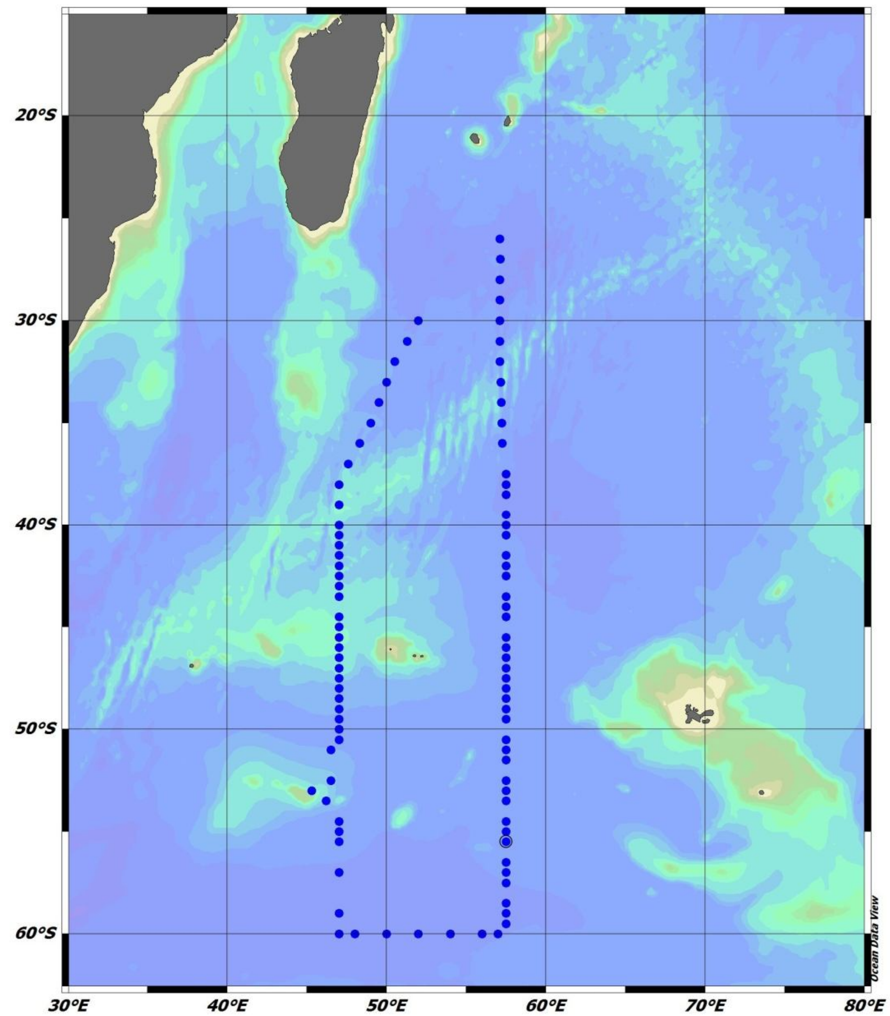


Figure 6: XCTD locations

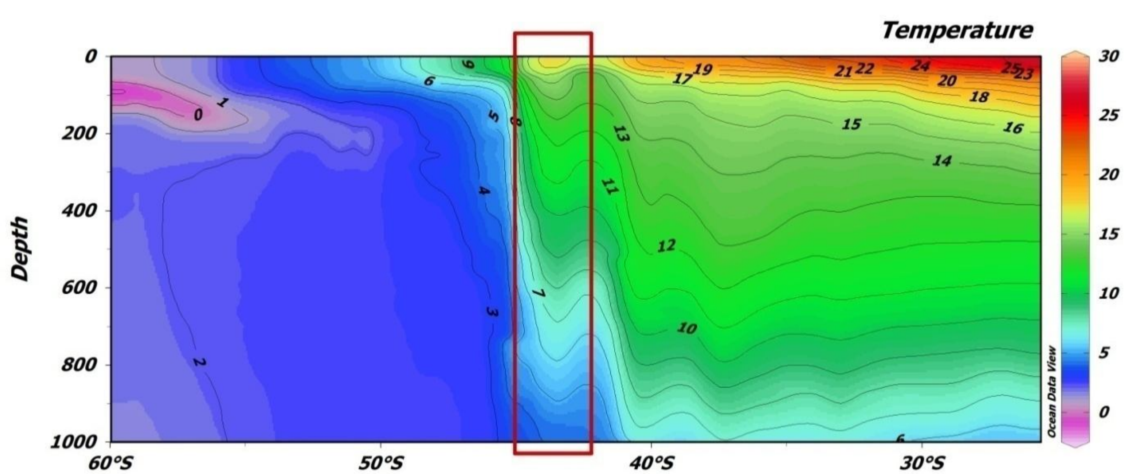


Figure 7: Vertical section of temperature along 57°30'E

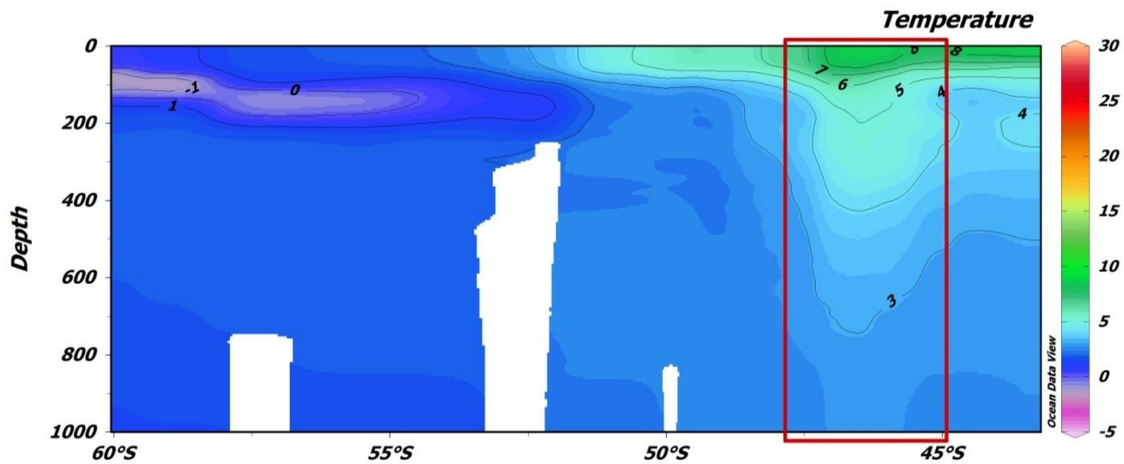


Figure 8: Vertical section of temperature along 47°E

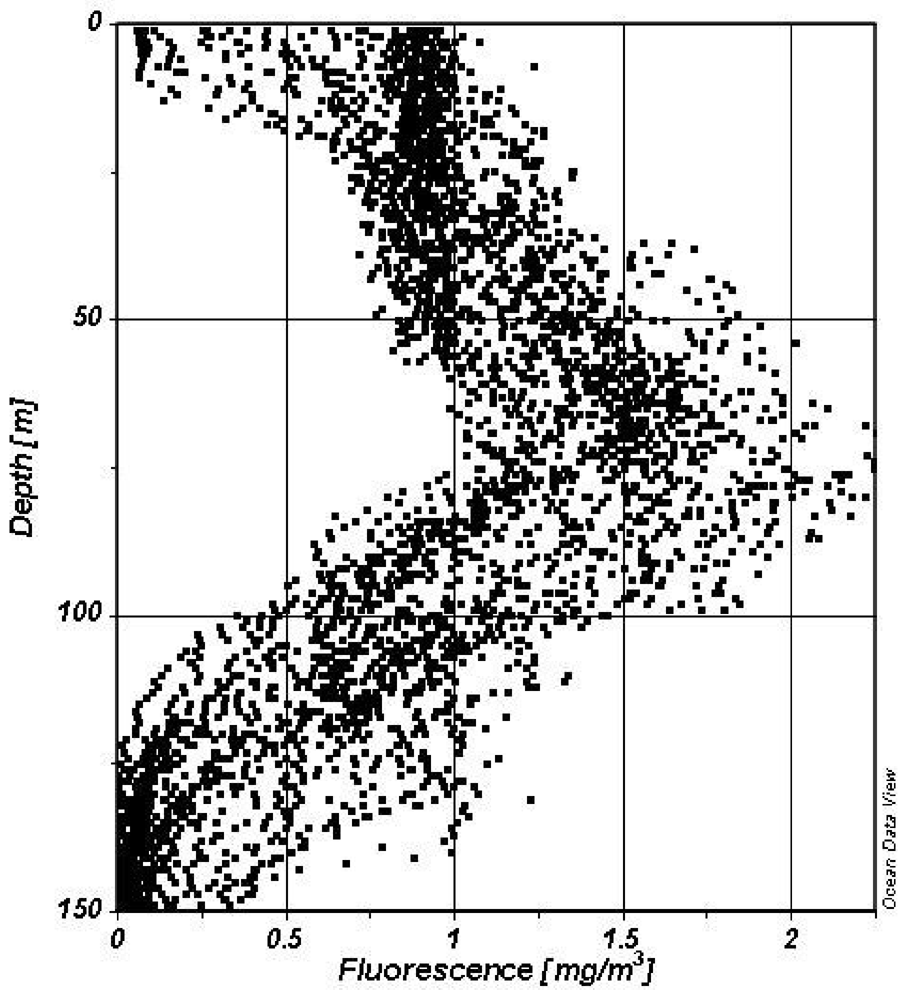


Figure 9: Scatter plot of Fluorescence at TS 1

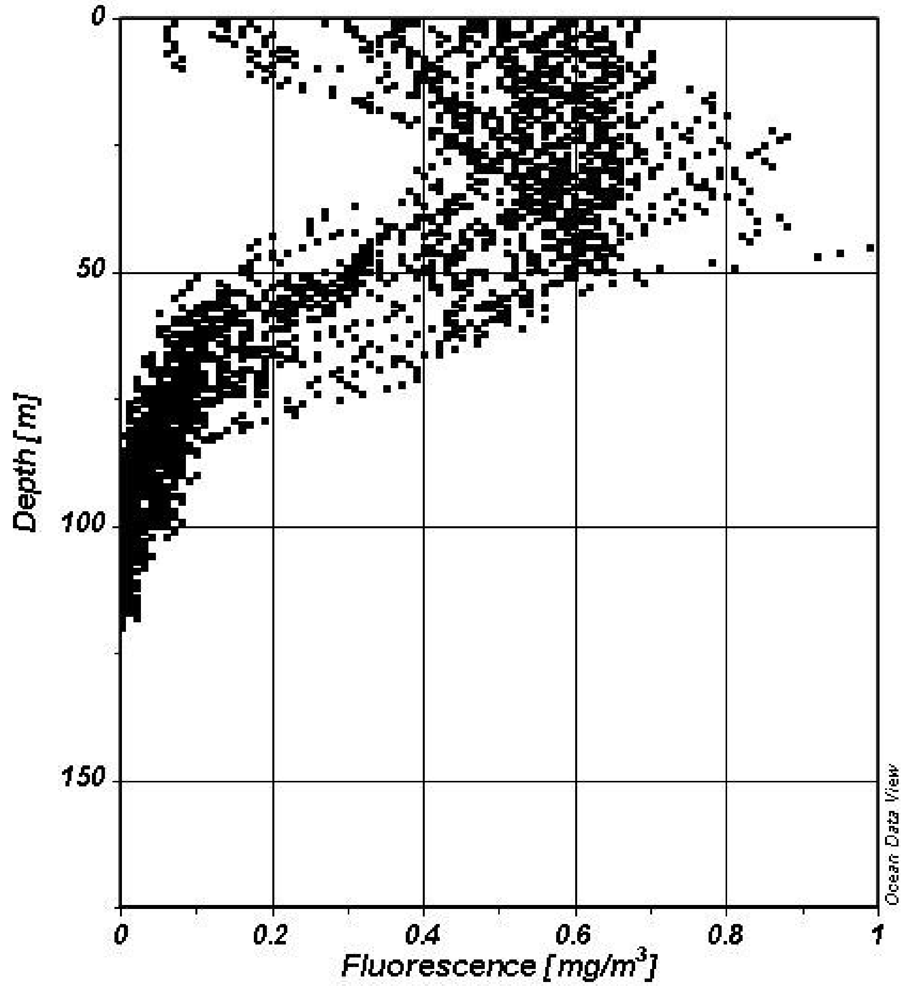


Figure 10: Scatter plot of Fluorescence at TS 2

Table 2: CTD cast location

Sr. No.	Latitude (°S)	Longitude (°E)	Depth Deployed
1	37	57° 30’	4500m
2	39	57° 30’	4500m
3	41	57° 30’	4500m
4	45	57° 30’	500m
5	48	57° 30’	4000m
6	50	57° 30’	4200m
7	51° 30’	57° 30’	500m (Time Series)
8	52	57° 30’	4900m
9	54	57° 30’	5000m
10	56	57° 30’	4000m
11	58	57° 30’	4500m
12	60	57° 30’	5000m
13	60	55	1000m
14	60	53	1000m

Sr. No.	Latitude (^{0}S)	Longitude (^{0}E)	Depth Deployed
15	60	51	1000m
16	60	49	1000m
17	60	47	5200m
18	58	47	4800m
19	56	47	4500m
20	54	47	4200m
21	50	47	3800m
22	48	47	3400m
23	46	47	1800m
24	44	47	2400m
25	42	47	500m(Time Series) 3568m

Table 3: XCTD deployment locations

Sr. No	Latitude (^{0}S)	Longitude (^{0}E)
1	26	57° 14’
2	27	57° 15’
3	28	57° 11’
4	29	57° 10’
5	30	57° 10’
6	31	57° 13’
7	32	57° 12’
8	33	57° 18’
9	34	57° 21’
10	35	57° 23’
11	36	57° 26’
12	37	57° 30’
13	37° 30’	57° 30’
14	38	57° 30’
15	38° 30’	57° 30’
16	39° 30’	57° 30’
17	40	57° 30’
18	40° 30’	57° 30’
19	41° 30’	57° 30’
20	42	57° 30’
21	42° 30’	57° 30’
22	43° 30’	57° 30’
23	44	57° 30’
24	44° 30’	57° 30’
25	45° 30’	57° 30’
26	46	57° 30’
27	46° 30’	57° 30’
28	47	57° 30’
29	47° 30’	57° 30’
30	48	57° 30’

Sr. No	Latitude (^{0}S)	Longitude (^{0}E)
31	48° 30’	57° 30’
32	49° 12’	57° 30’
33	49° 30’	57° 30’
34	50° 30’	57° 30’
35	51	57° 30’
36	51° 30’	57° 30’
37	52° 30’	57° 30’
38	53	57° 30’
39	53° 30’	57° 30’
40	54° 30’	57° 30’
41	55	57° 30’
42	55° 30’	57° 30’
43	56° 30’	57° 30’
44	57	57° 30’
45	57° 30’	57° 30’
46	58° 33’	57° 30’
47	59	57° 30’
48	59° 30’	57° 30’
49	60	57
50	60° 10’	56
51	60	54
52	60	52
53	60	50
54	60	48
55	60	47
56	59	47
57	57	47
58	55° 30’	47
59	55	47
60	54° 30’	47
61	53° 30’	46° 11’
62	53	45° 20’
63	52° 30’	46° 37’
64	51	46° 45’
65	50° 30’	46° 57’
66	50	47
67	49° 30’	47
68	49	47
69	48° 30’	47
70	48	47
71	47° 30’	47
72	47	47
73	46° 30’	47
74	46	47
75	45° 30’	47
76	45	47
77	44° 30’	47

Sr. No	Latitude (^{0}S)	Longitude (^{0}E)
78	43° 30’	47
79	43	47
80	42° 30’	47
81	42	47
82	41° 30’	47
83	41	47
84	40° 30’	47

6.3 Chemistry

6.3.1 SO biogeochemical cycling (NCAOR, Goa)

SO is of considerable interest since it plays a significant role in global biogeochemical cycling and climate change. It also plays a vital role in the context of the global carbon cycle and glacial-interglacial changes in atmospheric *p*CO2, due to its large nutrient reservoir, which generally never gets exhausted in open-ocean systems. Hence, large areas of SO may be regarded as typical high-nutrient/low chlorophyll regions (HNLC), probably due to limiting micronutrients such as iron (Martin et al., 1990). It is characterized by large seasonal variability in its environmental characteristics and is one of the important areas to be studied since the waters of the SO directly or indirectly affect the Indian Ocean and thus the Indian climatic regime. SO characterized by different fronts and frontal regions plays an active role in governing the distribution of chemical and biological parameters within the ocean. The present information on the chemistry of the SO is very limited particularly, in Indian sector. Therefore considerable interest exists in exploration of Indian sector of SO with special regards to chemistry in addition to biological and physical parameters.

It is well established that the trace metals such as iron (Fe), limit the productivity in the ocean. Several iron enrichment experiments in HNLC region have shown an increase in phytoplankton growth indicating its importance in phytoplankton productivity. Considerable effort has been made in understanding the relationship between phytoplankton productivity and availability of iron, particularly in high nutrient and low chlorophyll (HNLC) regions of the open ocean. It is important to note here that other trace metals such as manganese, cobalt, zinc, cadmium and copper also play crucial role in phytoplankton growth. In order to gain better insight into of the role of these trace metals in productivity it becomes essential to understand their effect in different combination in addition to solitary effect. During this expedition, two important metals viz. Fe and Co and their combinations were chosen to understand their effect on phytoplankton biomass accumulation

Objectives:-

1. To understand the effect of critical elements (Fe and Co) on phytoplankton productivity.
2. To study the distribution of nutrients, total carbon and trace metals in the SO.
3. To study the variation of total suspended matter and its component composition over a day at two frontal regions.

Work carried out onboard

Total of 26 stations were covered along the 57° E, 60° S and 47°E from the Indian Sector of SO. Two litres of water was collected at different depths (0, 10, 30, 50, 75, 100, 120, 200, 500 and 1000 m) along 57°E and 60°S and also at deeper depths along 47°E. Sub-samples were taken for different parameters such as dissolved oxygen (DO), pH, nutrients and trace metals. Dissolved oxygen and pH was measured by Winkler method and pH meter, respectively. Water samples collected for trace metals were filtered and were preserved with acid while water samples collected for nutrients were deep frozen and were analysed onboard using Auto analyser.

Time Series Studies

Two time series observations were conducted at Polar Front I and Sub Tropical Front. Water samples were collected up to 200 m depth for three days at 6 hourly intervals. Water samples were analysed for pH, DO and nutrients onboard. Apart from these, five litres of water was collected for total suspended matter studies at six depths which were filtered using pre-weighed millipore filters (pore size - 0.45 µm) and were dried in oven at 60°C. Filters were stored for analysis of suspended matter and its component composition.

Mesocosm Experiment

Three mesocosm experiments were conducted at polar front (56°45'S, 47°E), Subtropical front (42°S, 47°E) and 34°S 47°E. 180 litre of water was collected at each front and the experiment was continued for five days. Trace metals such as Fe, Co and mixture of Fe and Co in the form of sulphides were added to these waters in order to understand their effect on phytoplankton productivity. Deck-incubation of water samples was carried out with proper aeration system. Sub-samples were taken on everyday including at zero hour for the analysis of pH, dissolved oxygen, nutrients, chlorophyll, trace metals, phytoplankton bacteria and N^{15} analysis. Samples collected for chlorophyll were filtered and were stored in liquid nitrogen for the analysis.

N^{15} Analysis

Water samples (60 ml at each station) were collected at five stations (35°52'S 57°26'E; 39°31'S 57°30'E; 49°38'S 57°47'E; 55°53'S 57°29'E; 60°S 47°30'E) in the dark bottles. Tracers such as nitrate, ammonia and urea were added to these samples and were incubated for 4 hr running seawater. After the incubation, sampleswere filtered using Millipore filters (0.7 µm) and filter papers were dried at 50°C and stored for isotopic analysis. Some preliminary results are present below.

pH generally varied from 7.85 to 8.57 from 37°S 57°30' to 60°S 57°30'E. It was generally higher in the upper water column (Fig. 11). Dissolved oxygen generally showed increase towards the south in the colder waters and was comparatively higher in the surface waters (Fig. 12).

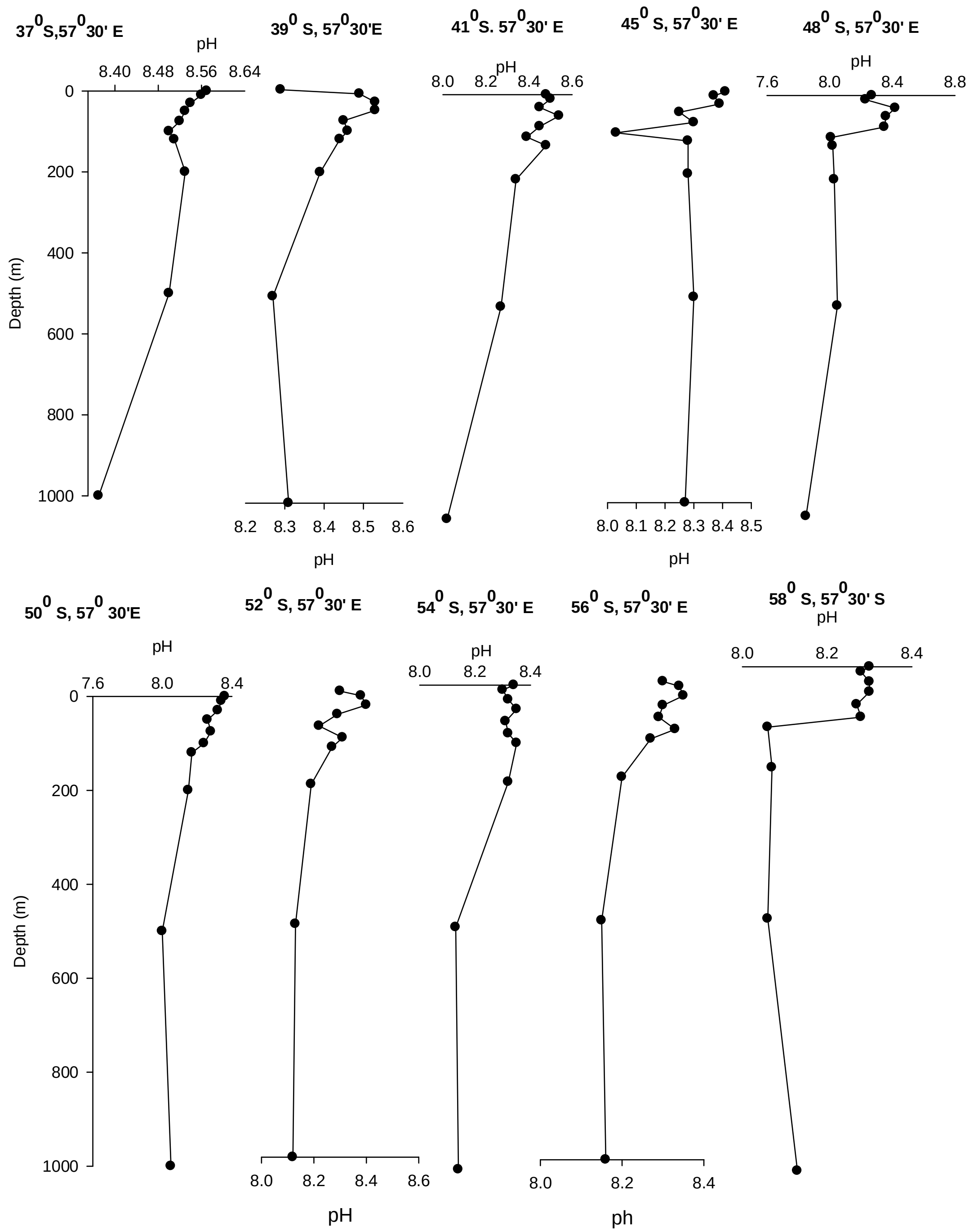


Figure 11: Variation of pH in water column along 37°S, 57°30’ to 58°S, 57°30’E.

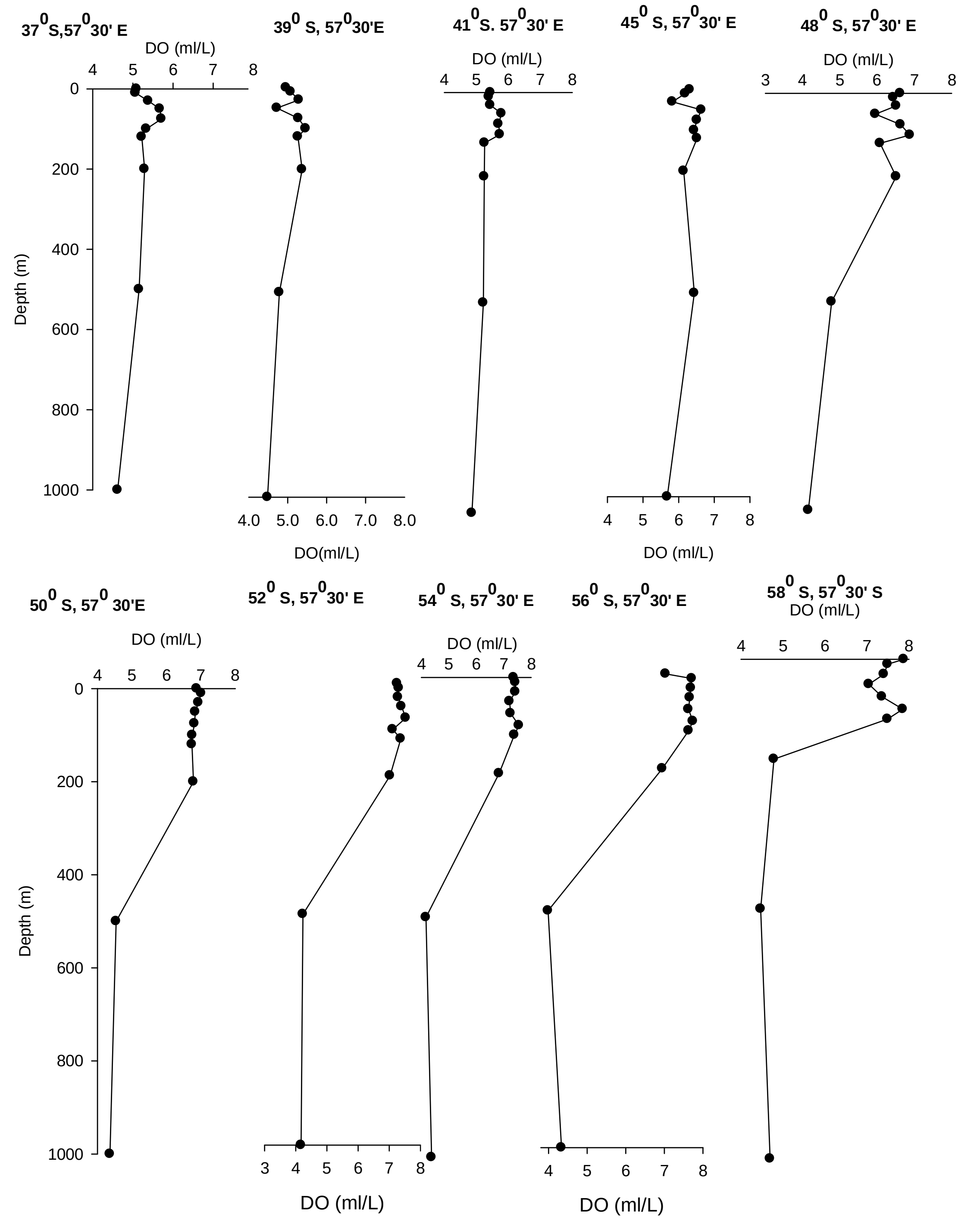


Figure 12: Variation of Dissolved Oxygen (DO) in water column along 37°S, 57°30' to 58°S, 57°30'E.

6.3.2 Bio optical properties of SO **(CIFT, Cochin)**

All water bodies, from clear-water oceans covering large areas to small, form an important part of natural environment. Oceans have the greatest influence on the climatic and synoptic conditions. They also influence the economy of nations and the quality of human life. This influence is essentially determined by dynamic, thermal, chemical, biological, geological and optical properties of the ocean. The water properties of different water bodies show great variability, connected with their limnological/optical type, season, cyclic change of biological activity and human impact. Optical properties are determined by optically active water constituents (in addition of water itself) that are called "water components". The consequences of the human impact and the respective changes in the water environment of the SO and the correlation of productivity with respect to the satellite data can be studied by *insitu* water colour component analysis of the SO.

Objectives

Measurements of inherent bio-optical properties of SO Waters.

1. To derive quantitative information on the types of substances present in the water and on their concentrations from variations in the spectral forms.
2. To derive algorithm to assess the productivity of the SO using the water colour components.

Sample collection and work done onboard

The station locations for the study of bio-optical measurements are shown in Fig. 5.Water samples were collected for analyzing inherent optical properties (IOP) like Coloured Dissolved Organic Matter (CDOM), Phytoplankton and Non Algal Particle (NAP) absorptions, Total Suspended Matter (TSM) absorbance, nutrients, salinity, plankton diversity, and trace metals from 23 stations at 6 depths (0 m, 30 m, 50 m,75 m,100 m and

DCM). At the time series stations water samples were collected at 3 hourly interval during the day time at 3 depths (0 m, 100 m and DCM) for 3 days .

CDOM absorption

Absorption of coloured Dissolved Organic Matter (CDOM, also called 'yellow substance') a_{CDOM} was measured with spectrophotometer (UV/Visible Spectrophotometer, in the range 190-800 nm) in water which was filtered through Whatman 0.2 μm filter, in a 10 cm cuvette against milliQ water and corrected for backscattering. Absorption spectra was approximated by a linear regression between the logarithm of a_{CDOM} against wavelength (λ) and expressed by the formula of Bricaud et al. (1981).

Phytoplankton and NAP absorptions

Five litre of seawater filtered under low vacuum pressure (<25 hPa) on 47 mm Whatman GF/F filters was used for absorption spectra measurement. The filter papers were kept at -40°C for further analysis at the concerned laboratories in mainland. The absorbance spectrum (dimensionless) of these filters (total particulate matter) relative to a blank filter saturated with sea water measured between 400 and 750 nm with 1 nm increment on dual beam UV-VIS spectrophotometer (Shimadzu) equipped with an integrating sphere will be measured. The optical density of detritus also will be measured after pigment extraction using 100% methanol (Kishino *et al*., 1985). These absorption spectra will be corrected for the pathlength amplification (β-effect) and will be converted into light absorption coefficients of the total particulate matter and detrital matter (ap(λ) and ad(λ), respectively) according to Cleveland and Weidemann (1993). The light absorption coefficient of phytoplankton ($a$ph(λ)) was obtained by subtracting ad(λ) from ap(λ) and the chlorophyll-specific light absorption coefficients of phytoplankton (a^*ph(λ)) was obtained by dividing $a$ph(λ) by the total chlorophyll a (TChl a) concentration.

Chlorophyll a concentration

Five litre water samples were collected from the euphotic layer at each station using a Niskin sampler and stored in cool and dark place for less than 5 hours before filtering. Aliquots (5 lts) were filtered, under low vacuum (<10 cm Hg), through GF/F (Whatman) glass filters to concentrate the particles for pigments determination and the filter papers were stored at -4°C. The filters were soaked in 90% acetone for 24 hr and refrigerated in darkness at 4^0C. Chlorophyll a concentration will be measured with Turner Design 10 AU Flourometer.

***6.3.3 Investigation of mass concentration of suspended particulate matter* (Goa University)**

The mass concentration of suspended particulate matter (SPM) in the ocean varies in different regions and at different depths due to various biotic and abiotic factors and is also influenced by geographical location, productivity and the dynamics of its water masses. Various processes such as biological activity, lithogenic inputs mostly clay and rock detritus through the melting of ice, submarine volcanic activity, hydrothermal and extra-terrestrial inputs determine the composition of SPM. Also, as a result of re-suspension of sediments, a large volume of lithogenic particles are transferred within the interior of the ocean.

Objectives

The knowledge of the distribution of SPM is an important prerequisite for the description and prediction of the ecological conditions. The fundamental physical and chemical properties of water may vary depending on the type and origin of SPM. The SPM in the water column regulates the penetration depth of light and therefore it is an important parameter influencing primary productivity. Elemental chemistry of SPM will help in understanding source of matter.

An attempt is thus being made in this expedition to:

i. Investigate the distribution of SPM,

ii. Components and chemistry of SPM and

iii. To understand source and processes operating in the region of the Indian sector of the SO, representing three zones i.e. Sub-Tropical, Sub-Antarctic and Antarctic zones.

Work carried out onboard

Surface water sampling (5L) was carried out at every 1° latitude interval for Suspended Particulate Matter (SPM) from 28°S to 60°S along 57°30'E and in the return track from 60°S to 28°S along longitude 47°E.

Additionally, water samples were collected at depths 100m, 200m and 1000m at latitudes 35°S, 40°S, 37°S, 41°S, 43°S, 45°S, 54°S, 55°S, 59°S and 60°S along 57°30'E in the onward track and at 35°S, 40°S, 43°S, 46°S, 54°S, 55°S, 59°S and 60°S along 47°E in the return track. Due to bad weather conditions observations could not be made at a few stations along both, onward and return tracks. The surface water samples were collected using a plastic bucket and transferred to plastic containers carefully to avoid metal contamination.. The water samples were filtered through pre-weighed Millipore membrane filters having pore size 0.45µm using a plastic filtration unit. One litre of the filtered water samples were stored in pre-cleaned plastic containers by adding 1ml of 30% HCl. The SPM and water samples will be analysed in the laboratory for SPM constituents, particulate and dissolved metals. Sea surface temperature and salinity data for surface water samples were collected. The sea surface temperature was measured using a bucket thermometer and salinity was determined using Autosal. Temperature and salinity of water samples for various depths were determined using a CTD profiler.

6.3.4 SO particle chemistry of the suspended matter and the seawater **(JNU, New Delhi)**

The sample collection was done keeping SST as the basis so as to target the fronts and zones along the cruise track. The water samples were collected in the Polyethylene cans from Niskin bottles and immediately after collection the water samples were filtered using millipore polycarbonate filters of 0.45μm pore size and 47 mm diameter to study the suspended particle chemistry of the SO. Filtered water was acidified with purified HCl to pH 2 for REE (Rare earth elements) analysis. The filters were then transferred to polypropylene petri dishes and stored at -20ºC in the deep freezer. The rare earth elements have chemical properties which make them an excellent natural probe of particle/solution interactions and redox reactions at surfaces. The coatings on suspended particles carry the chemical imprint of the in situ removal of REEs from seawater and that extensive REE fractionation between particle coatings and seawater develop in the upper water column. The chemical properties of REEs may be used to model the particle/solution interactions of trace elements in sea water. The locations of seawater sample collection are given in the table 4:

Table 4: Location of seawater for REE$_S$ Studies

Sample no.	Latitude	Longitude	Sea surface temperature (in degree)
1	45º S	57º 30' E	12
2	48º S	57º 30' E	8
3	50º S	57º 30' E	6
4	54º S	57º 30' E	2.7
5	60 º S	57º 30' E	1
6	60º S	53º 30' E	1
7	60º S	47º E	0.5
8	50º S	47º E	5.5
9	46º S	47º E	8.5
10	42º S	47º E	16.5

In order to study the Particulate organic carbon (POC) and particulate organic nitrogen (PON) two liters of seawater was filtered using GF/F filters and filters were kept in the oven at 60° for 30 minutes before storing them at -20ºC in the deep freezer. POC and PON measurements allow quantifying and understanding carbon fluxes in the ocean. High concentrations of POC and PON are found during phytoplankton blooms near the ocean surface, under upwelling conditions, in coastal waters. Lower concentrations are observed, e.g., in oligotrophic subtropical gyres or during intervals between blooms. Very low concentrations of suspended POM are usually encountered in the deeper ocean. It has been observed that the occurrence of POM is less in deep water in comparison to the upper water column.

6.4 Biology

6.4.1 Primary production and associated biological process and the variation of biological and physicochemical components with time (NCAOR, Goa)

SO is characterised by perennially high macronutrient levels yet low and constant levels of phytoplankton stocks. Fronts and water masses of the SO greatly influence the regulation of biological production at the global scale. At the low temperatures experienced in the Antarctica, a large temporal lag often exists between phytoplankton and mesozooplankton production, which has been suggested to cause the phytoplankton biomass to increase substantially. Microzooplankton is ubiquitous and since many are similar in size to their phytoplankton prey, it may be possible that they exert some control on certain phytoplankton functional groups, at least during the growing season. In the present expedition the main biological components of water column intended to be studied are: Chlorophyll *a*, primary production, phytoplankton, mesozooplankton and microzooplankton.

Phytoplankton are the photosynthetic cells and primary producers of the oceans.

Mesozooplankton are organism in the size range between 200 μm and 2 cm. Zooplankton play significant role in the food chain they serve as a link between primary production (phytoplankton) and tertiary production (nektonic components).

Microzooplankton are organisms in the size range between 20 μm and 200 μm and serve as important food source for mesozooplankton when phytoplankton abundance is low, particularly in oligotrophic waters .

Objectives

1. To understand the primary production and associated biological process of the water column in the fronts and zones of SO.
2. Time-series observation to understand the role of physicochemical components on the biological productivity at selected fronts.

Materials and methods

Water samples were collected along 57º30'E and 47ºE at every alternate degree latitude (Table 5). A total of seven constant depths were sampled for phytoplankton, microzooplankton and chlorophyll (Chl *a*) from surface to 120 m (0 m, 10 m, 30 m, 50 m, 75 m, 100 m and 120 m) and one at the Depth of Chlorophyll maxima (DCM). Mesozooplankton was sampled at four depths i.e., Mixed layer depth (MLD), MLD to 150 m, 150-300 m and 300 – 500 m. To study the surface distribution of mesozooplankton samples were also collected using Bongo net. For primary productivity (PP) study, samples were collected from 5 depths (0 m, 30 m, 50 m, 75 m, 120 m and at DCM.

Times series studies

Water samples were collected from Polar front I and Sub-tropical front (Table 5) for 3 days. Samples for phytoplankton, microzooplankton and mesozooplankton were collected at 6 hourly interval, while samples for chlorophyll were collected at 3 hourly interval. Samples for PP was collected at dawn and incubated on deck for 8 to 10 hours. Depths of sampling of all parameters were as mentioned above.

Onboard analysis

Water column biology

Phytoplankton

The samples were collected in 500 ml bottles and preserved immediately with Lugols iodine solution. These samples will be later concentrated to 20 ml and the plankton will identified under the microscope using a sedgewick rafter counting chamber.

Microzooplankton

Five litres of water sample was collected and filtered through 200 µm mesh and further concentrated by siphoning through 20 µm mesh to approx. 300 ml and preserved with Lugols iodine containing strontium sulphate and formalin. These samples will be further concentrated to 20 to 30 ml by siphoning through 20 µm mesh prior to microscopic analysis.

Chlorophyll

2 liters of water was collected and filtered onboard using a GF/F filter paper (pore size?). The filter papers were immediately stored in -40ºC for further analysis. Later in laboratory, pigment extraction will be carried out b**y** adding 10 ml of 10% acetone. These samples will be placed in refrigerator for approximately 18 to 24 hours, and readings will be obtained in Turners flourimeter (flourimetric method).

Mesozooplankton

Zooplankton samples were preserved in formalin. Using volume displacement method biomass will be estimated. The sample after biomass estimation will be split using a Folsom splitter and a part will be analysed in lab under microscope using a Bogorov's chamber.

Table 5: Station locations of biological operations

Sr. No.	Station No	Latitude	Longitude	Date	Biological Parameters
1	1	37°00’S	57° 30’E	30-01-2011	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
2	2	39°00’S	57° 30’E	31-01-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
3	3	41°00’S	57° 30’E	01-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
4	5	4 5° 00’S	57° 30’E	04-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
5	6	4 8° 00’S	57° 30’E	06-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
6	7	50° 00’S	57° 30’E	07-02-11	Chlorophyll,Phytoplankton, Microzooplankton, Mesozooplankton
7	7a	51° 25’S	57° 30’E	08-02-11	**TIME SERIES STATION** → Primary productivity, Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
8	8	52° 00’S	57° 30’E	11-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
9	9	54° 00’S	57° 30’E	12-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
10	10	56° 00’S	57° 30’E	13-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
11	11	58° 00’S	57° 30’E	14-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
12	12	60° 00’S	57° 30’E	15-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton, Fe experiment.
13	13	60° 00’S	55° 06’E	15-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
14	14	60° 00’S	53° 00’E	16-02-11	Primary productivity, Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
15	15	60° 00’S	51° 04’E	16-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
16	16	60° 00’S	49° 00’E	17-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
17	17	60° 00’S	47° 00’E	17-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
18	18	58° 00’S	47° 00’E	18-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
19	19	56° 00’S	47° 00’E	19-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
20	20	54° 00’S	47° 00’E	20-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
21	22	50° 00’S	47° 00’E	23-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
22	23	47°.57’S	47° 00’E	24-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
23	24	46° 00’S	47° 00’E	24-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
24	25	44° 00’S	47° 00’E	25-02-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
25	26	42° 00’S	47° 00’E	26-02-11	**TIME SERIES STATION** → Primary productivity, Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton
26	27	40° 00’S	47° 00’E	02-03-11	Chlorophyll, Phytoplankton, Microzooplankton, Mesozooplankton

Primary productivity

Primary production can be measured using the ^{14}C method (Steemann – Nielsen, 1952). 1 ml of the radioactive isotope was added to the water sample (250 ml – 1 dark and 2 light bottles). The samples were incubated onboard using density filters for minimum 6 hours and later filtered through GF/F filter paper of 25 mm diameter. In order to remove inorganic C the filter papers were exposed to acid fumes for few seconds. The ^{14}C incorporated in the algal cell will be measured later in lab by adding the scintillation cocktail and by counting in the scintillation counter.

Experimental studies onboard

Iron is the major trace metal required for the growth of phytoplankton. However, this micronutrient is limiting in the SO. To test the growth of phytoplankton with addition of iron we attempted an experiment onboard. Surface water from Polar front was collected and filtered using 200 μm and later with 20 μm mesh to remove mesozooplankton and microzooplankton, respectively. Iron sulphate in nanomolar concentration was added to these samples to study the variation in phytoplankton. These samples were incubated on deck for 5 days. Samples for chlorophyll, nutrients and phytoplankton were collected every twelve hours for 5 days to observe the growth of phytoplankton. These samples were stored using the standard protocols (phytoplankton-Lugols iodine; chlorophyll – stored at -40°C) for further analysis.

6.4.2 ACC fronts Interactions around Crozet Plateau regulating phytotoplankton assemblage (Institute of Oceanography, Furg, Brazil)

The Indian Sector of the SO is historically under sampled. The Antarctic Circumpolar Current (ACC) system is extremely important for global climate studies, as it acts as a physical barrier for exchange of polar and subtropical waters. At least three main fronts associated with the ACC dynamics occur in the area: the Sub-Antarctic Front, the Polar Front, and the Southern ACC Front [Orsi et al. 1995]. On the other hand, the ACC system connects all the major global ocean basins, acting as an important link to heat, salt, and momentum fluxes.

Frontal systems are very dynamic and their spatial and temporal variability have been studied by remote sensing in the past [ex. Moore et al, 1999]. Visible (ex. SeaWiFS, MODIS, MERIS) and infrared (ex. AVHRR, MODIS) sensors can be used to monitor the position of these dynamical fronts (Figure 13) in different time scales. Since Images are currently freely distributed by several spatial agencies (ex. NASA and ESA), remote sensing is an important tool which can be used in conjunction with classical hydrographical data in the SO. Further, the formation of fronts can separate various ecological zones and show biological gradients, where subtropical and subantarctic species can be found [Rodhouse *et al*., 2001].

Objectives

- To identify the main ocean fronts position in the Indian Ocean sector of the SO.
- To study the composition of phytoplankton communities in the region, using the photosynthetic pigments as taxonomical biomarkers;
- To determine possible relationship between phytoplankton communities (through pigment composition) and the ACC fronts zones;
- To study the main ocean fronts variability by MODIS ocean color and thermal infrared images.

CTD stations, sampling and posterior analysis

Twenty seven hydrographic stations were successfully sampled (Figure 13 &14) from 37°S to 60°S along 57°30’E and from 60°S to 40°S along 47°E.

Seawater samples were collected from depths 0 m, 10 m, 30 m, 50 m, 100 m, 120 m and the DCM.These samples were filtered on board for pigment determination by the High Performance Liquid Chromatography (HPLC) methodology, and the filtered material were adequately stored on freezer (-17.5°C) and liquid nitrogen. The GOAL (Brazilian High Latitudes Oceanographic Group) group will determine the phytoplankton pigments by HPLC analysis in the laboratory.

The CTD data will be used to determine the water masses, the position of the fronts, and the geotropic transport in the study area. Ocean color and infrared images will used to study the frontal system variability over different time scales.

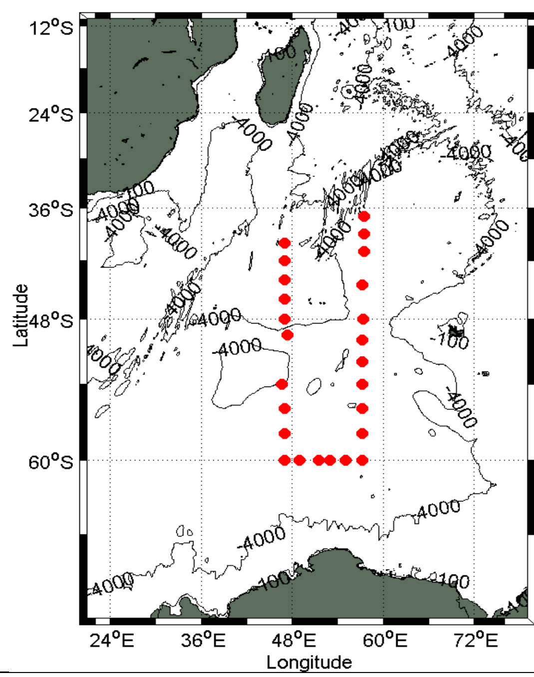


Figure 13. Map of Indian sector of the SO. The red circles show the hydrographic stations locations.

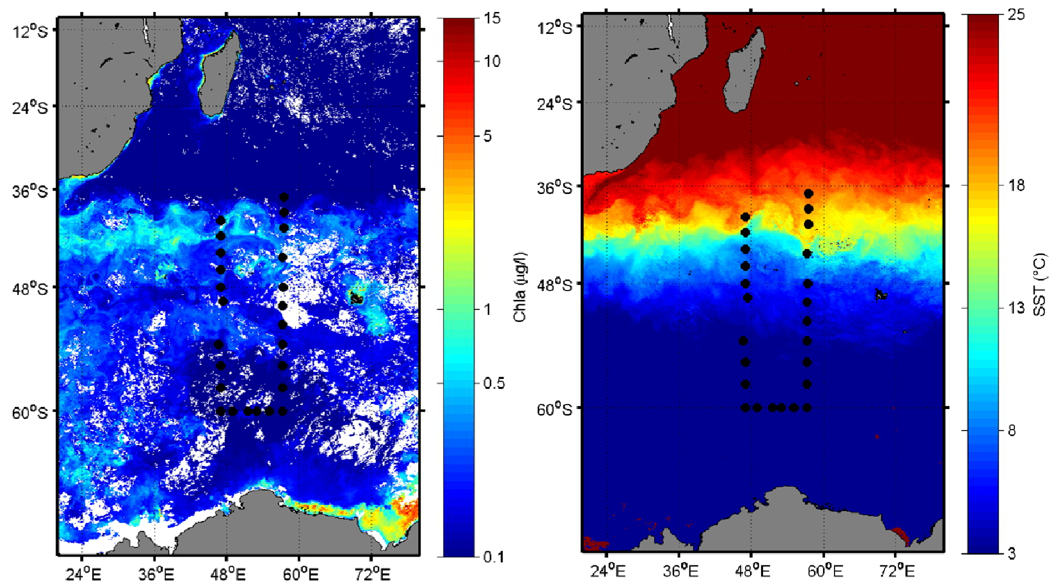


Figure 14. Monthly mean chlorophyll-a concentration (left) and sea surface temperature (right) images for February 2010 derived from MODIS-Aqua sensor. The images also show the deployed grid of CTD stations during the cruise.

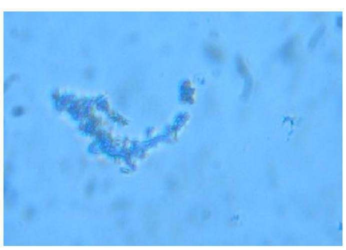
6.4.3 Microalgal diversity in SO (BIT, Ranchi Jharkhand)

Objectives

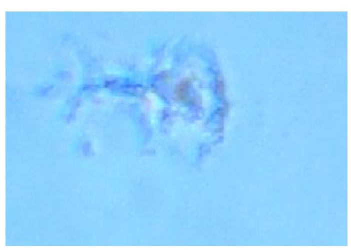
1. Prevalence of algal microflora in SO and their characterization.
2. Metabolic potential and variability studies in different latitudes and various zones and fronts (Subtropical, Polar and sub Antarctic).
3. Other Microbiological observation of novel bacterial communities in deep sea water and their biological significance.
4. Microbial products for development of drugs and medicines from isolates as mentioned above.
5. Enzymological studies of selected bacteria as mentioned above.
6. Environmental genome sequencing and metagenomic studies of SO.

Samples were collected from different temperature based zones and fronts namely subtropical, Polar and sub-antarctic. However, a few samples were also collected for surface sea water and DCM depth to understand the diversity change of microalgae due to change in temperature and salinity. All samples (500 ml sea water) from different depths (0, 50, 75, 100, 120, 200, 300, 500 m and deep sea water) were collected in seal pack PP round neck bottles and were kept at desired temperature ranging between 1°C and 22°C. Further a few samples were examined onboard under microscopic to look for presence of microalgal cells. This study was initiated with some deep sea samples and interestingly we found existence of microalgae (see microphotograph; Figure 15) at higher depths (>500 m). The photograph was taken with low quality magnification through micro-microscope (Figure 16). The primary observation study set up is presented in Figure 2. Further study will be carried out after this expedition and some interesting results could be farmed out with more details of cell morphology. Collected samples will be studied under Leica stereo zoom Florescence Microscope. Pure colonies will be grown in media for identification and characterization in due course.

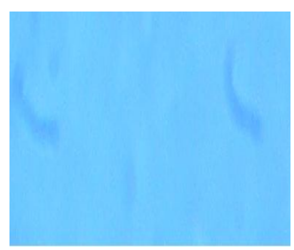
A few deep sea water samples (depth > 1000 m) were also collected for identification and characterization of novel bacterial communities in deep sea water and their biological significance towards understanding release of novel enzymes and other bio-products through them. These studies will be completed shortly in the laboratory. Two hundred litres of surface seawater was collected at 42°S 47°E for environmental genome sequencing and metagenomic studies which will be first of its kind from SO.



PSRB-1(Unidentified microalgal cells)



PSRB-2(Unidentified microalgal cells)



PSRB-2(Unidentified microalgal cells in cluster)

Figure 15: Few Microalgal species (10X)

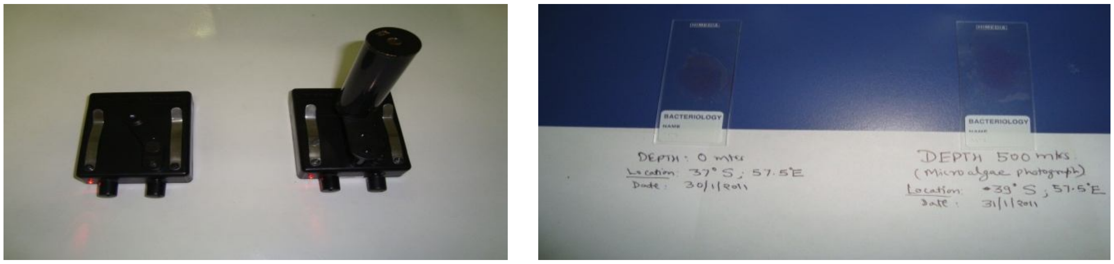


Figure 16: Setup of Micromicroscope (10X) and slide preparation for primary screening of microalgae

6.4.4 Surveys for marine mammals, megafauna and seabirds (CMFRI, Cochi)

The objectives of the present investigation are the following:

1. Interpretation of oceanographic parameters related to the distribution, relative abundance and migratory patterns of marine mammals along different oceanic realm.
2. The biodiversity analysis of sea birds from SO
3. Investigation of oceanic parameters in relation to the distributional patterns of megafauna including deep sea corals along with changes in seabed geography.

Methodology

Opportunistic visual surveys for marine mammals were conducted onboard ORV Sagar Nidhi with a Nikon handheld binocular and a Nikon D80 camera fitted with Nikon 70-300 mm lens, during daylight hours. On sighting a cetacean date, time, position, depth at the area of sighting, wind speed, sea-state, visibility, and sea surface temperature were recorded. Details on the cetaceans such as species, morphology, behaviour, group size and associated animals were also noted. The observed cetaceans were identified to the lowest taxonomic level possible. Published pictures of the whole animal along with species description on morphological characters and behaviour were compared with the observed characters for identification of the sighted individual. Whenever necessary, the species identifications were validated later with the photographs taken onboard. If a cetacean is unmistakably identified based on the reported description up to species or generic level, its name was recorded. In case there was a doubt, the name was mentioned as “possible”. Animals that could not be identified were recorded as “unidentified”.

To study the megafaunal diversity, samples were collected using van Veen Grab at three different locations and a box corer was operated in the places where grab samples were not obtained.

1. Marine Mammals

A total of 45 days with average of 10 hr of daily effort was made for the opportunistic survey. Minke whale *Balaenoptera bonaerensis* and Killer whale *Orcinus orca* were the two confirmed species sighted during the cruise. More dedicated survey up to 67º S is necessary for bring out the distribution and migratory pattern of marine mammals in SO. The details of marine mammals observed during the cruise are given in table 6.

Table 6: Details of marine mammal sightings onboard ORV Sagar Nidhi

Date	Time (hrs)	Position	Species	Group size	Behaviour
01.02.11	15:45	39°39’S & 57°29’E	Unidentified	1	Spouting
07.02.11	07:30	49°34’S & 57°53’E	*Balaenoptera bonaerensis*	1	Travelling
16.02.11	14:30	60°00’S & 52°18.E	*Balaenoptera bonaerensis*	5	Travelling
17.02.11	18:00	59°59’S & 48°29’E	Unidentified	1	Spouting
21.02.11	16:30	52°58’S & 45°04’E	*Orcinus orca*	6	Travelling
22.02.11	18.30	52°47’S & 45°55’E	Unidentified	1	Spouting

2. Sea Birds

Seabirds are the only components of the marine ecosystems that can be easily monitored. They are top predators whose demography and population abundances are directly influenced by the availability of their prey such as krill, fish or squid which are themselves directly influenced by abiotic components. Changes in the population sizes or demographic parameters of several seabird species have already been related to large-scale climatic changes occurring in the marine ecosystems worldwide and more specifically to abiotic components such as sea-surface temperature or air temperature anomalies. Hence, sea birds of SO were observed during the marine mammal observation. The biodiversity analysis of sea birds of SO along the cruise track will be done using diversity indices. The following species of sea birds were encountered along the cruise track.

1. Wandering Albatross

2. Black browed Albatross

3. Light mantled sooty Albatross

4. Giant Petrels

5. Black Petrels

3. Megafaunal Studies

To study the megafaunal diversity of SO, samples were collected using Grab. Sampling was done at three different locations. Deep sea coral fragments and gorgonids were collected on 789 m depth at 32°S. The occurrence of coral fragment indicates the presence of cold water corals in the area. Sediment samples were collected for further analysis. Agassiz trawl and Dredge would be suitable to collect benthic organisms in these areas. The sampling areas would be the best area to collect marine epibenthic animals. True reputation of benthos could be collected from these areas by using Agassiz trawl and dredge. The details of grab/corer sampling are given in table 7.

Table 7: Sampling locations of grab/corer

Date	Position	Depth (M)	Fauna
29.01.11	32°43’S & 57°17’E	789	1. Deep sea coral fragments 2. Gorgonid
21.02.11	52°59’S & 45°15’E	483	Samples were not collected in spite of two attempts.
21.02.11	52°58’S & 45°04’E	329	Manganese nodules were collected and no faunal collection
02.03.11	38°28’S & 46°47’E	658	Two deep sea corals and a glass sponge

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7. Conclusion and Recommendations

The Indian Scientific Expedition to SO 2011 started on 24th January 2011 at 2100 hr IST from Port Luis, Mauritius. This cruise was conducted mainly to collect multi-disciplinary data and samples from the Subtropical to Polar Regions of the Indian sector of the SO. A team of 15 Scientists from various organizations and Universities across the country, two scientists from Federal University of Rio Grande, Brazil and three engineers from NORINCO Pvt. Ltd. (Norway - India Collaboration), Chennai participated in this cruise.

During this expedition the entire team onboard carried out scientific operations successfully at twenty seven stations using CTD (Conductivity, Temperature, Depth), MPN (Multi Plankton Net) and Bongo net for the collection of hydrographic profiles, water samples, phytoplankton and zooplankton. Continuous underway ship measurements such as Acoustic Doppler Current Profiler, Automatic Weather Station, Multi-beam, Echo-sounder and Sub-bottom profiler were operated for ocean currents, atmospheric parameters and bathymetric data collection. Two meridional sections (57°30'E and 47°00'E) and one zonal section (60°00'S) were covered during this expedition starting from 37°00'S 57°30'E. Two time series observations for a period of three days in the Subtropical (42°00'S 47°00'E) and the Polar Regions (51°30'S 57°30'E) were also successfully completed by operating CTD at three hourly intervals, MPN and Bongo net at six hourly intervals. Samplings were done from 30th January to 4th March 2011 and all metrological observations and sea surface data collections were made at three hourly intervals in the entire cruise track starting from the outside EEZ (Exclusive Economic Zone) of Mauritius. Due to bad weather and high sea state conditions the operations could not be carried out at two station locations at 43°00'S 57°30'E and 52°00'S 48°00'E. One shallow cast (upto 100 meter sample depth) and one deep cast (upto near bottom sample depth) were carried out at most of the stations. Grab sampling and corer operations were carried out to collect the bottom sediments at the shallower depth of three different places. For salinity and temperature profiles 115 numbers of XCTDs probes were also launched in the entire cruise track between 27°00’S 57°30’E and 30°00’S 48°00’E out of which 95 profiles were obtained successfully.

The observations made from the Indian sector of the SO during the austral summer 2011 will help to understand the inter-annual variations in biogeochemistry, hydrodynamics, and air-se interaction from the subtropical to polar regimes. The tremendous efforts taken by the expedition members for data collection in extreme weather and high sea state conditions are really admirable and the data and samples collected will definitely help to understand the various process occurring in the unknown areas of SO.

Recommendations

1. CTD with rosette system onboard should be rectified properly or replaced with another unit. Water sample collection for small depth intervals in the upper ocean is very important for productivity related studies. This instrument is crucial for most of the expeditions related to the studies on biogeochemistry.
2. Provisions for the storage of helium/hydrogen cylinders as well as launching of weather balloons should be made.
3. Temperature and salinity values of TSG compared with the Bucket Thermometer and CTD/XCTD showed the following differences: a. In the tropical area ~ 0.5°C b. In the subtropical to Polar regions the difference is 2 to 4°C. This problem with the sensor has to be rectified. To avoid the influence of the re-circulated warm water from the engine it is suggested to shift the sensor of TSG from the present

position where it is fixed. This may help to rectify the above mentioned error noticed with the temperature data.

4. A spare CTD and MPN should be available onboard for replacement in case of fault and defect or loss.

5. A XBT/XCTD data acquisition system and launcher should be made available onboard. A multiparameter probe should be made available for analysis of water properties onboard.

6. The Milli-Q unit needs to be checked and calibrated

7. Weighing Balance suitable for onboard applications.

8. Certain instruments like Muffle furnace, TOC analyser, LICOR analyser (for continuous atmospheric CO_2 measurements).

9. Accessible rain guage.

10. Provision for pumping of large amount surface water should be made available.

11. Availability of a portable ICPMS.

12. Filteration units with adequate spares and holders with larger capacity should be made available.

13. Fluorimeter for analysis of chlorophyll onboard.

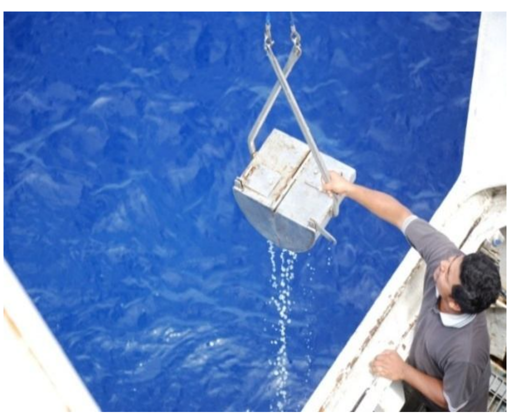
Few Photographs taken onboard ORV Sagar Nidhi

CTD

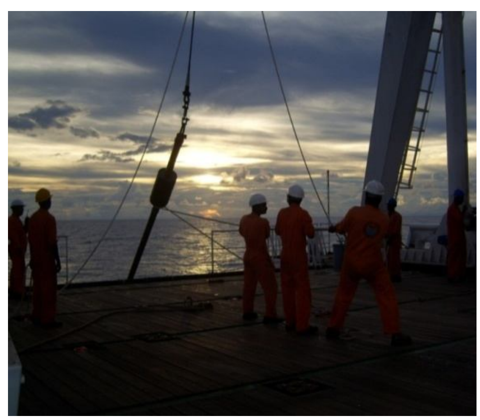
XCTD

MULTIPLE PLANKTON NET

BONGO NET



VAN -VEEN GRAB



GRAVITY CORER OPERATION

ARGO FLOAT DEPLOYMENT

MULTIPLE FILTRATION UNIT

DEEP FREEZER & STORAGE IN LIQUID NITROGEN

MEMBERS OF THE EXPEDITION ISOE 2011