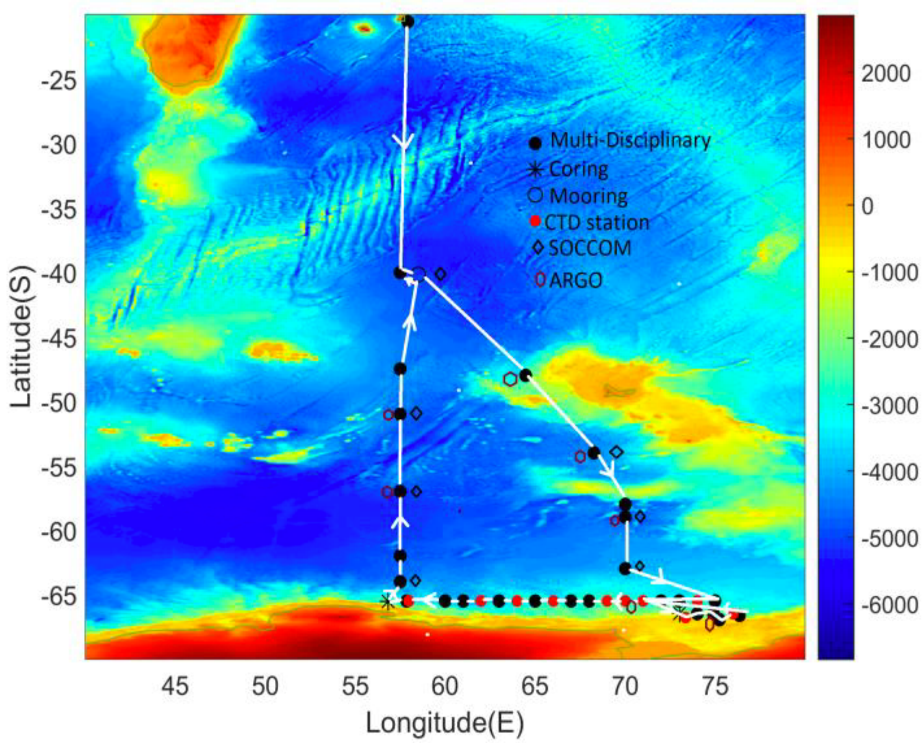
CRUISE REPORT: I07S

(Updated AUG 2021)



Highlights

Cruise Summary Information

Section Designation	**I07S**
Expedition designation (ExpoCodes)	**91AA20171209**
Chief Scientists	**Rajani Kanta Mishra** **A. S. Mahajan**
Dates	2017 DEC 09 - 2018 FEB 04
Ship	MV S.A. Agulhas
Ports of call	Port Louis, Mauritius
Geographic Boundaries	-40.035 57.4133 70.0983 -63.0233
Stations	36 CTD stations
Floats and drifters deployed	7 Argo floats deployed
Moorings deployed or recovered	1 sediment trap mooring

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Final report assembly by Jerry Kappa, SIO/UCSD

CRUISE REPORT

10th Indian Sector Of Southern Ocean Expedition (SOE-10)

(8th December, 2017-4th February 2018; on board MV S.A Agulhas)

ESSO-National Centre for Antarctic and Ocean Research

Earth System Science organization, Ministry of Earth Sciences, Govt. of India

Headland Sada, Vasco-da-Gama, Goa-403804

Preface

Indian research initiatives in Indian sector of southern ocean realm highlights the significance of the region to climatic variability's and its importance in our understanding the climate at large. To date, we have undertaken ten multi-institutional and multidisciplinary expeditions to the southern ocean. The 2017-18 expedition to Indian sector of the Southern Ocean (ISOE-10), which incidentally was the 10th expedition to the region and hence, it complete the one decade of observations from the southern ocean realm. The expedition commenced on 9th December 2017 from Port Louis, Mauritius on board a South African charter research vessel MV S. A. Agulhas. The National Centre for Antarctic and Ocean Research (NCAOR), Goa under aegis of Ministry of Earth Sciences (MoES), ESSO and eight collaborative research institutes/universities from India and aboard were participated in the expedition. The team consisted of 42 participants, out of which 36 scientists from various organization such as Indian Institute of Tropical Management (IITM), National Remote Sensing Centre (NRSC), Indian Institute of Science (IISC), Indian Institute of Technology (IIT),Central Marine Fishery Research Institute (CMFRI), Scripps Institute of Oceanography (SIO), Goa University (GU), Amity University (AMITY), Cochin University (CU), 2 engineers from NORINCO Pvt Ltd and 4 seamen from Dharmaraj Marine Services Pvt Ltd. In addition to this 66 personals were from South African Maritime Service Agency (SAMSA) participated in expedition including captain, chief engineer, ice pilot, officers, doctor, crew members and cadets/trainee. The main objectives of the expedition was to retrieval of mooring (from last year station), observations at coastal region including Prydz Bay (68^{0}S), time series observation at coastal waters, sediment sampling through coring and other multidisciplinary observations. As per the cruise plan the above mentioned series of scientific observations/experiments were conducted and implemented successfully. This 10th SOE was one of the successful expedition in terms of number of stations that were sampled, 3 days time series observation at coastal waters, sediment cores from target areas and in addition to this, several atmospheric observations were successfully carried out throughout the expedition. In the expedition, total 36 numbers of multidisciplinary and CTD stations observations carried out from 40^{0}S to the coastal waters of Antarctica 67^{0}S through Subtropical Front (STF), SubAntarctic Front (SAF) and Polar Front(SAF). After reaching 65^0 30'S and 76^{0}E, the CTD and multidisciplinary observations were carried out towards westward upto 71^{0}E and then due to pack ice on the surface, the vessel proceeded upto 66^0 30'S and 76^0E for time series @ 12 hrs observations (i.e. 3 days, 7 observations). Further due to pack ice on the surface returned to 65^0 30'S and 71^0E and thereafter every 2 degree interval from 71^0E moved westward up to 57^0 30'E for multidisciplinary observations (Figure 1) and every 1 degree interval for CTD operations. The continuous operations of underwater CTD (UCTD) without stopping the vessel from east to westward carried out to study Antarctic bottom water (AABW) influence on water mass dynamics and biogeochemistry of the Indian sector of the SO. In addition to this, the continuous measurement of atmospheric parameters of temperature, humidity, pressure, wind speed, wind direction, black carbon, trace gases, rain fall, water vapour and light along the cruise track carried out for upper atmospheric observation for Air-sea interaction from tropical to polar regions. The entire observations carried out about 59 days in expedition, after completions of voyage the vessel MV S.A Agulhas port called at port Louis, Mauritius on 4th February 2018 and all scientific team along with samples and their scientific instruments disembarked on 5th February 2018.

The SOE-10 expedition was one of the most complexes, due to its severe cyclonic weather and high sea state condition. However the scientific operations was almost not abandon countless of the stations due to every participant's sincere effort, thorough planning and persistence made this expedition one of the most successful ever the Southern expedition had been earlier and therefore could succeed to cover highest number of stations/observations. The marine ecosystems of the Southern Ocean, so difficult to explore because of its remoteness and extreme climate, are amongst the Earth's most unusual yet least known ecosystems and hence need to be investigated what factors govern its distribution and abundance. The sample and the data were collected from the region would definitely generating high quality datasets, which could be utilized for exhilarating publication for better understanding the hydrodynamics and biogeochemical process in the Indian sector of Southern Ocean further. The research in SO has progressed significantly over recent years, driven by new investigative methods, improved sensor equipment and stronger modelling approaches, which would help us to compare and utilize our regional quality data ever more pertinent answers to understanding biogeochemical process and the role of Indian sector SO in global climatic variation

Acknowledgements

On behalf of all participants, I would like to take this opportunity to articulate our heartfelt gratefulness to Dr. M. Rajeevan, Secretary, MoES, Dr. M. Ravichandran, Director NCAOR, Dr. N. Anlilkumar, Group director, Ocean Sciences, NCAOR for facilitating all the services and support for successful completion of the expedition. I am thankful to, Master, Ice pilot, Chief engineer, Officers and Cadets/Crew of MV S. A. Agulhas for their support and coordination during the expedition. The Ocean science group staff Ms. Prafila N. Gaonkar and Mr. Ganesh Chandavale, provided service towards all logistic activities from the beginning to the end of the expedition, for which we are thankful to them. None of this voyage would have been successful without the whole hearted cooperation's and enthusiasm of scientific staffs, NORINCO engineers, seamen and vessel crew members. NORINCO engineers have done excellent job of maintaining and handling onboard scientific instruments, and also devising a new core head so as to facilitate the coring operation and we are sincerely grateful to them for their service. We are also gratified to Dr. D. Mahapatro and his team, National Centre for Medium Range Weather Forecast (NCMRWF), for sending daily weather forecast during the entire expedition period. I would like to thank Mr. Arnaud Teycheney, General Manager, Inchcape Shipping Services Ltd, Mauritius for all logistic support with transporting, loading, unloading of instruments container, during expedition. We acknowledged Mr.Rakesh Rao, Documentary film maker who made the documentary film for scientific expedition first time to the Indian SO. At the last but not least, we express our appreciation to the all NCAOR staff, finance, procurement division and our all family members those directly/indirectly involved to the success of the expedition.

Dr. Rajani Kanta Mishra
(Leader of the Expedition, SOE-10)

Contents

1.Introduction

The Southern Ocean (SO) is known as source and sink of atmospheric CO_2 over glacial-interglacial climate cycles, but the relative importance of physical, chemical and biological mechanisms driving the magnitude of CO_2 exchange are under speculate the Antarctic Circumpolar Current (ACC), an ocean current that flows from west to east around Antarctica, plays a crucial role in global ocean circulation and transports drastic heat across the ocean and hence understanding this current system has a major role in the climatic variability studies. SO is the site for deep and intermediate water mixing and therefore provides the fundamental link between the upper and lower layers of global ocean circulation. As a result of the significance of SO in earths climatic pattern and any change in the region would have global impacts.

The limited observations and evidence suggest that the SO changes due to changing of warming, freshening, accumulation of anthropogenic carbon dioxide and acidification, which lead to changes the destination of marine biota from tropical to polar and vice versa. As a result the marine biota shows shifting, adaptation or extinction with respect to climatic variations. However more systematic scientific investigation should be carried out for comprehensive study of physical and biogeochemical process which are essential to better understanding of the regional hydrodynamics and biogeochemical process to climatic variations at the region of the Indian sector of SO and global.

For more comprehensive understanding the influence of SO on the climatic variabilities, the National Centre for Antarctic and Ocean Research (NCAOR), Goa under the aegis of Ministry of Earth Sciences (MoES), Govt of India, is the nodal agency for the planning and coordinating the scientific expeditions to the 10^{th} of the Indian sector of the SO (SOE-10) during 2017-18 to conduct multidisciplinary research in the various frontal regions starts from 40^0S and the Prydz Bay, coastal water of Antractica. Up to now the NCAOR had successfully launched nine expedition during (2004-2017) collaborating with many national and international research organization/universities to understand the atmosphere-ocean interaction, hydrodynamics and biogeochemistry of across the STF to PF of Indian sector of SO based on the multidisciplinary data collected from the meridional sections (48^0E and 57^0 30’E). The previous expeditions results are quite exciting and provided adequate baseline information on physical and biogeochemical procees to detail understanding the interannual variation in the climatic and ecosystem.

In view of keeping above endeavour the ongoing expedition to extend the scientific understanding in the SOE-10 was launched on 9th December, 2017, Port Louis Mauritius. The expedition was aimed to cover the frontal regions starts from various frontal regions 40^{0}S to the Prydz Bay, coastal water of Antractica to study the physical, chemical, biological and air-sea interactions. During the expedition the various instruments were operated and carried out on board experiments (Table 1) and the parameters were measured by various institutes/organizations in (Table 2).

2.Objectives

In the 10th expedition to the Southern Ocean (SOE-10) the following objectives were identified to understand the role of Indian sector of the SO and its influence on the climatic variabilities in the regional and global.

- To understand the hydrodynamics, current structure and volume transport between PF and Prydz Bay region of coastal Antarctica
- To understand source of freshwater, water mass characterstics with special reference to AABW and comutation of meridional transport
- Understand the spatial and temporal varability of diapcnal micing in the Indian sector of the SO.
- Impact of near-shore processes on nutrient distribution and cycling with special emphasis on Si
- Distribution of TCO2, Co2 fluxes and its links to biology and hydrodynamics within STF, PF and coastal waters.
- Distribution, source and molecular fractionation of organic matter:TOC, DOC, POC, TEP, Carbohydrate and protein distribution including isotopic studies of Particulate Organic Matter (POM)
- Microbial carbon uptake, respiration and demend: Glucose uptake,Oxygen respiration and Biomass.
- Cross validation of 14C(radioactive) and 13C (stable)-based PP estimates so as to standarze the latter method in the study area
- To identify the environmental controls on variability in PP and phytoplankton physiology by FRRF study, and to develop a fluorescence-based method for estimating daily pp
- Role of new productivity in carbon sequestration. Investigate the role of preferntial nutrient-uptake on PP
- To characterize the underwaterlight fields through measurementsof inherent optical properties(IOP) and appreant optical properties (AOP) of the study area.
- To study the phytoplankton community structure using different techniques (microscopy, HPLC and flowcytometry)
- To understand the micro and meso zooplankton community structure and diversity with reference to the biogeochemical properties
- Collection of sediment core at coastal area of Antarctica for diatom and dinoflagellates cyst analysis.
- Observation of atmospheric trace gases (halogens), black carbon contents and aerosols.
- Study of δD, $\delta^{18}O$ and deuterium excess in water vapour, precipitation and surface water
- Study of In-situ and satellite optical characterization of Southern Ocean waters

3. Study Area and Sampling

The 10th expedition to the Indian sector of the Southern Ocean (SOE-10) was carried out by on board research vessel MV S.A.Agulhas of South Africa. The expedition started at 15:30 hrs (local time) on 9th December 2017 from Port Louis, Mauritius and ended at 19:30 hrs (local time) on 4th February 2018 at Port Louis, Mauritius. From port Louis the vessel stirred first to the mooring station (40^0 11' S and 58^0 30'E) for retrival of subsurface sediment trap (deployed last year). Then the vessel proceeded southward a diagonal path towards the outer region of Kerguelen Island and collected samples for multidisciplinary observations (Figure), continued through Polar front (PF), covering three multidisciplinary observations with deployment of ARGO and Bio-ARGO floats to study the water mass dynamics. After reaching to the 65^0 30'S and 76^{0}E, the observation carried out for the CTD and multidisciplinary stations towards westward upto 71^{0}E. Because of packed ice on the surface, the vessel proceeded till 66^0 30'S and 76^{0}E for time series @ 12 hrs observations (i.e. 3 days, 7 observations), afterthat the vessel could not move further south due to the similar packed ice on the surface and hence returned to 65^0 30'S and 71^0 E towards westward and thereafter every 2 degree interval from 71^{0}E to 57 30'E the multidisciplinary observations were carried out (Figure), and every 1 degree interval for CTD operations including the continuous operations of underwater CTD (UCTD) without stopping the vessel from west to eastward to understand the Antarctic bottom water (AABW) influence if any for water mass dynamics and biogeochemistry of the Indian sector of the SO. In total, more than 22 stations were multidisciplinary observations, 14 stations were only CTD cast observations, 1 time series observation for 3 days at coastal Antarctica near to Prydz Bay and nearly more than 50 surface water samples collected along the cruise track for study of physico chemical parameters, trace gases, phytoplankton diversity, biomass, paleoocenographic studies etc.

During the expedition the major instruments operations/measurements were carried out such as (i) Profiling of water sampling of shallow cast below 1000m depth and depper cast about 4000m depth water column under multidisciplinary observations using CTD, (ii) UCTD profile operations upto 400m depth in water column without stopping the vessel for high resolution of salinity, temperature and depth, (iii) firing of XCTDs to study the same profile high resolution of salinity and temperature depth, (iv) Lowering ADCP for profiling the Ocean currents (v) Microprofiler operations upto 300m depth for turbulence studies (v) operation of multiple plankton net (MPN) upto 1000m for mesozooplankton studies (vi) bongonet haul operations in the surface at 3knots speed for collecting surface mesozooplankton (vii) radiometer profiler operation upto 200 meter for underwater optical measurement (viii) operation of Inhertied optical profiler (IOP) upto 200 meters to study the back scattering, fluorescence, nutrients, and CTD measurement (ix) operation of 500µ mesh size and IKMT net for surface and depth upto 1000m in watercolumn for larval and para-larval studies in cephalopods (x) operation of squid jigg for study of growth of squids in different frontal regions (xi) study of atmospheric trace gases by MAX-DOAS and ozone monitor (xii) measurement of vertical structre of atmosphere through radiosonde launching (xiii) measurement of balck carbon, aerosol and AOD measurement (xiv) measurement of green house analyzer (CO2, CH4, H20) (xv) measurement of dust track monitor (xvi) measurement through microwave rain radar to study rain rate, water vapour and dropsize etc, (xvii) deployment of Argo and Bio-Argo floats for profiling study of the water column in particular period. For the experimental study of physical, chemical, biological and microbiological the water samples and the water filtered filter paper were stored in the respective temperature and brought to the NCAOR laboratory, and sent to the participant's institutes for further analysis and study the physical and biogeochemical processes in the Indian sector of SO.

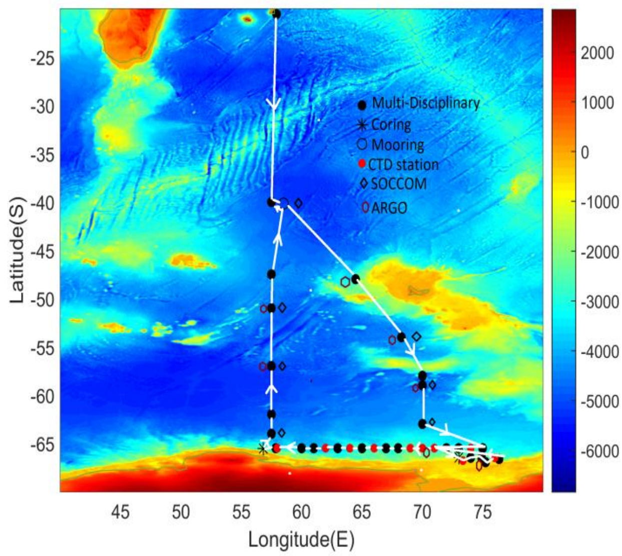

Figure : A cruise track showing multidisciplinary observations during SOE-10. The arrows shows the sequence of stations operations.

4. Participants

4.1 Scientific Participants

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4.2 Ship Crew Participants

Sl No.	Surname	Name	Desigination
1	Barnes	Michael	**Master**
2	Conradie	Carl	**Chief Officer**
3	Gwexa	Zikhona	2nd Officer
4	Carolus	Evert	3rd Officer
5	Nxumalo	Nosipho	3rd Officer
6	Davies	Lionel	**Chief Engineer**
7	Mzobe	Thulani	2nd Engineer
8	Myesi	Dumisani	3rd Engineer
9	Ntukuva	Mthuthuzeli	4th Engineer
10	Stoffels	Daniel	Electrical
11	Jardine	Abdul Aziz	Bosun
12	Davids	Angelo	Able Seamen
13	February	Ashely	Able Seamen
14	Lewis	Howard	Able Seamen
15	Gqokoma	Thembalethu	OS
16	Solomons	Sulaiman	Chippy
17	Trout	Rodney	GP Tr
18	Pute	Ntsikelelo	GP Tr
19	Cokile	Thando	GP Tr
20	Layman	Rudolph	MA
21	Van Der Horst	RiCardo	Oiler
22	Mafunda	Nkosingiphile	Oiler
23	Lackay	Randall	Oiler
24	Ntyutyana	Wandile	GP Tr. Eng
25	Van Rooy	Clint	Chief Steward
26	Khan	Mogamat	Chef
27	Dryden	Bernardo	Cook
28	Naidoo	Ricardo	Cook
29	Cay	Jeffrey	Cook
30	Laubser	Wesley	Utility Steward
31	Sive	Jime	Utility Steward
32	Daniels	Strafford	Utility Steward
33	Mbarane	Lwazi	Utility Steward
34	Davids	Juan	Cat Assist
35	Walker	Abduragmaan	Cat. Assist
36	Pieters	Merwyn	Snr.Trng Off
37	Paulse	Steven	Trng Off
38	Tate	Kevin	Ice Pilot
39	Hirowitz	Zoelle	Doctor

5. Preliminery Results

5.1 Hydrodynamics of the Indian Ocean sector of the Southern Ocean

Introduction

The Southern Ocean (SO) is the formation region of several water masses that ventilate the deep and intermediate depths of the world ocean. These water masses play an important role in the global climate system as reservoirs of heat, freshwater and dissolved gases and act as a dominant mechanism on variations in the global climate.The SO's remoteness and hostile environment make observations very difficult. As a result, many processes in the SO and its response to climate changeremain unknown mainly due to the lack of high resolution sea-truth data. Hence, sustained observations from this region are essential for understanding how the physical processes in SO will respond to climate change.

The general circulation of the SO is dominated by the eastward flow of the Antarctic Circumpolar Current (ACC), which is the crossroads of the global ocean's water masses, connecting the Atlantic, Pacific, and Indian Oceans as well as connecting the deep ocean to the surface.The key driver for this circulation is the westerly winds which are the one of strongest mean surface winds on earth. Studies have shown that the ACC does not flow eastward as a homogeneous wide flow but is concentred on a number of quasi-permanent circumpolar jets and these jets are limited by fronts that dynamically separate water masses. The Indian Ocean sector of Southern Ocean (IOSO)has a complicated frontal system which consists of multiple branches and filaments with these fronts exhibiting considerable latitudinal and inter-annual variability. The major fronts across ACC in the IOSO are Agulhas Retroflection Current (ARF), Sub-Tropical fronts (STF), Sub-Antarctic front (SAF), Polar front (PF), Southern Antarctic Circumpolar Current Front (SACCF), Southern Boundary of ACC (SB) and Antarctic Slope Front (ASF). One of the objectives of the present expedition was to occupy hydrographic measurements along a comparatively new track near to Kergulean Island and also along 57°30′S, a track which has been monitored in the previous SO expeditions since 2004 to understand the frontal dynamics and water mass variability in the IOSO using various art of oceanographic instruments such as CTD, Underway CTD (UCTD) and XCTD.

Further, the recent observations from SO reveal a rapid reduction in salinity and density of AABW. Based on the SO Expedition (SOE) 2006 and 2010 data, Anilkumar et al., 2015 have reported the rapid freshening of the AABW in the IOSO. To understand the recent rate of freshening of the deep and intermediate water masses in the IOSO, deep CTD profiles, the depths which cannot be covered by global ARGO floats, were collected across various fronts from 65◦S to 40◦S along 57◦30'E. Also, the recent studies have reported that (Katsumata et al, 2014) the larger signals of warming and freshening of deep and intermediate water masses occurring in the coastal regions of the Antarctica. Hence, in continuation of 9th SOE (2016-17), the 10th SOE is also planned in the coastal waters of Antarctica particularly in the Prydz Bay (PB) to understand its role on the IOSO circulation and water mass dynamics.

The PB, in East Antarctica, in the IOSO is a triangular-shaped embayment covering an area of about 80,000 km^2. This region plays a crucial role in SO circulation, bottom and deep water formation, carbon sequestration and biological productivity. Compared to the Antarctic Peninsula, the Weddell and Ross Seas, relatively little attention has been paid to understand the complex physical processes occurring in the PB. In the 9th SOE, an attempt was made to understand the hydrodynamics of PB based on high resolution hydrographic data along two zonal sections (68◦S and 65◦S) across the PB. The data collected from the above expedition has provided the base line information about the hydrodynamics of the PB during summer. Also, in the 9th SOE it was observed that the upper layers of the PB was warm and stratified which could be due to the seasonal or interannual variability of the winds and other related processes in the region (unpublished data). Hence, a one time observation may not be sufficient to understand the complex processes occurring in this area. Moreover, inter-annual data would be helpful to understand the hydrography of the PB in more detail. Considering this, it was proposed to re-visit the PB for intense measurements during the 10th SOE with the following objectives;

Objectives

The present expedition is the India's second consecutive field campaign to the PB with the following major objectives;

- The role of upper ocean stratification in the dynamics of Prydz Bay: An in-sight through repeat hydrography
- The watermass structure and their possible pathways in the Prydz Bay
- The Antarctic Bottom Water (AABW) in the IOSO and its rate of freshening and possible causes
- Frontal characterization using high resolution Underway CTD (UCTD) and XCTD data
- Estimation of micro-scale mixing in the Prydz Bay

Methodology/ Work carried out onboard

Sea Surface Temperature (SST) and Sea surface Salinity (SSS)

Sea surface temperature (SST) and surface salinity (SSS) sample has been collected along the ship track at 6-hourly interval starting from 27°S (10th December 2017) to 27°S (4th February 2018). SST has been measured with the help of an outboard thermometer (Friedrich Theodore, accuracy: ±0.5). The samples for SSS has been analysed using a shipborne salinometer (Autosal, Guildline 8400A). The data would be helpful to understand the spatial variability of SST and SSS across the various fronts in the SO along the ship track.

Study of hydrodynamics in the PB and IOSO

To understand the hydrodynamics of the PB and the rate of freshening of deep and intermediate water masses in the IOSO, a 911 plus CTD (make: Sea-Bird Electronics, USA; temperature: ±0.001°C, conductivity: ±0.0001 S/m and depth:±0.005% of the full scale, Fig.1) with accessory sensors (PAR, DO, Fluorescence) was operated. The locations of the CTD stations are given in Table 1. In addition to understand the thermohaline structure in the IOSO, XCTD's (Make: Tsurumi-Seki Co. TSK Ltd., Yokohama, Japan. Type: XCTD-1; precision 72% of depth, 70.03 mS/cm for conductivity and 70.02◦C for temperature) were operated at 0.5-degree along the return track. XCTD probes are the easy and effective means to collect temperature-salinity profiles in the ocean from a moving platform. These probes are expendable in nature, less time consuming and cost effective. The details of the XCTD locations are given in Table.2.

Table I: Operation details for CTD, Microstructure Profiler and Lowered-ADCP

Date	Station	Latitude (°S)	Longitude (°E)	CTD/ (O. Depth)	Micro Profiler/ (O.Depth)	LADCP/ (O.Depth)
15-12-17	1	39º59.7622'	57º30.0520'	√ (2000m)	√ (300m)	
20-12-17	2	47º59.87'	64º27.91'	√ (1500m)		
23-12-17	3	54º02.3091'	68º10.2166'	√ (1500m)		√ 200m
25-12-17	4	58º	69º59.6578'	√ (2000m)		√ (Stationary at 20m)
26-12-17	5	58º59.9400'	69º59.9807'	√ (2000m)		
27-12-17	6	63º00.8815'	69º59.2440'	√ (2000m)	√ (300m)	√ (Stationary at 20m)
30-12-17	7	65º30.1071'	75º00.5247'	√ (2000m)	√ (300m)	√ (Stationary at 20m)

30-12-17	8	65º31.6184'	74º02.4923'	√ (1000m)		
31-12-17	9	65º30.1458'	72º59.7367'	√ (2000m)	√ (300m)	√ (1000m)
31-12-17	10	65º31.2944'	72º04.9539'	√ (1000m)		
01-01-18	11	66º49.371'	73º22.974'	√(400m)	√ (200m)	√ (Stationary at 20m)
02-01-18	12	66º30.1484'	73º59.7537'	√(1000m)		
02-01-18	13	66º27.6923'	74º54.1781'	√(2000m)	√ (200m)	√ (Stationary at 20m)
03-01-18	14	66º30'	76º	√(900m)		
03-01-18	15 TS0	66º38.8160'	76º22.8112'	√(1500m)	√ (200m)	√ (200m)
03-01-18	15 TS0	66º37.3055'	76º23.1879'	√(500m)		
03-01-18	15 TS1	66º34.65'	76º24.38'	√(500m)	√ (200m)	√ (1000m)
04-01-18	15 TS2	66º33.8078'	76º25.2299'	√(500m)	√ (200m)	√ (1000m)
04-01-18	15 TS3	66º33.24'	76º22.05'	√(500m)	√ (200m)	√ (1000m)
05-01-18	15 TS4	66º37.1253'	76º18.9531'	√(500m)		√ (1000m)
05-01-18	15 TS5	66º39.0197'	76º19.6592'	√(500m)	√ (200m)	√ (1000m)
06-01-18	15 TS6	66º38.9315'	76º16.5000'	√(500m)	√ (200m)	√ (1000m)
07-01-18	16	66º57.5809'	75º15.9446'	√(300m)		
08-01-18	17	65º30.0301'	70º59.5514'	√ (2000m)	√ (250m)	√ (1000m)
08-01-18	18	65º30.0568'	70º01.9623'	√ (1000m)		
09-01-18	19	65º30.0820'	68º59.7539'	√ (2000m)	√ (190m)	√ (1000m)
09-01-18	20	65º30'	68º'	√ (1000m)		
10-01-18	21	65º29.8293'	67º00.2680'	√ (2000m)	√ (250m)	√ (1000m)
10-01-18	22	65º30'	66º00'	√ (1000m)		
11-01-18	23	65º29.8412'	64º59.6328'	√ (2000m)	√ (250m)	√ (1000m)
11-01-18	24	65º30.0126'	64º00.2736'	√ (745m)		
12-01-18	25	65º29.9033'	63º00.1505'	√ (2000m)	√ (250m)	√ (1000m)
12-01-18	26	65º30.2624'	61º59.7338'	√ (1000m)		
13-01-18	27	65º30.0534'	61º00.2150'	√ (2000m)	√ (250m)	√ (1000m)
13-01-18	28	65º30	60º00	√ (1000m)		
14-01-18	29	65º33.7641’	58º00.5873’	√ (2000m)		
15-01-18	30	65º31.8500’	57º51.1063’	√ (2500m)	√ (280m)	√ (1000m)
16-01-18	31	64º00.1227’	57º30.1212’	√ (3900m)		√ (1000m)
17-01-18	32	62º00.13’	57º29.98’	√ (4020m)		
21-01-18	33	56º59.24’	57º30.45’	√ (4000m)		√ (1000m)
24-01-18	34	51º00’	57º30’	√ (4000m)	√ (250m)	√ (1000m)
25-01-18	35	47º29.6900’	57º30.0289’	√ (4000m)		√ (1000m)
29-01-18	36	39º59.5986’	57º30.2831’	√ (4000m)	√ (250m)	

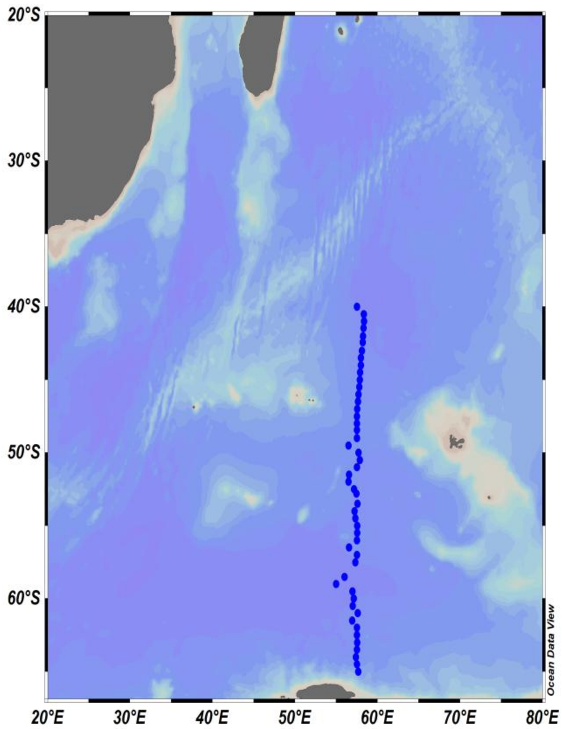

Figure 1. Locations along the return track where XCTD's were deployed

Table 2: XCTD deployment location

Sr.No.	Date	Latitude(°S)	Longitude(°E)
1	15-01-2018	65°	57°41'
2	16-01-2018	64°30'	57°30'
3	16-01-2018	64°	57°24'
4	16-01-2018	63°30'	57°30'
5	17-01-2018	63°	57°33'
6	17-01-2018	62°30'	57°30'
7	17-01-2018	62°	57°30'
8	17-01-2018	61°30'	56°56'
9	19-01-2018	61°	57°37'
10	19-01-2018	60°30'	57°
11	19-01-2018	60°	57°08'
12	19-01-2018	59°30'	56°29'
13	20-01-2018	59°	55°
14	20-01-2018	58°30'	56°12'
15	21-01-2018	57°30'	57°31'
16	21-01-2018	57°	57°30'
17	22-01-2018	56°30'	56°33'
18	22-01-2018	56°	57°30'
19	22-01-2018	55°30'	57°33'
20	22-01-2018	55°	57°33'
21	22-01-2018	54°30'	57°20'

22	22-01-2018	54°	57°14'
23	23-01-2018	53°30'	57°35'
24	23-01-2018	52°50'	57°27'
25	23-01-2018	52°30'	57°10'
26	23-01-2018	52°	56°30'
27	23-01-2018	51°30'	56°34'
28	24-01-2018	51°	57°30'
29	24-01-2018	50°30'	57°51'
30	24-01-2018	50°	57°43'
31	25-01-2018	49°30'	56°30'
32	25-01-2018	49°	57°30'
33	25-01-2018	48°26'	57°30'
34	25-01-2018	48°	57°30'
35	25-01-2018	47°30'	57°30'
36	26-01-2018	47°	57°33'
37	26-01-2018	46°30'	57°38'
38	26-01-2018	46°	57°43'
39	26-01-2018	45°30'	57°48'
40	26-01-2018	45°	57°52'
41	26-01-2018	44°30'	57°54'
42	26-01-2018	44°	58°
43	27-01-2018	43°30'	58°
44	27-01-2018	43°	58° 07'
45	27-01-2018	42°26'	58°12'
46	27-01-2018	42°	58°15'
47	27-01-2018	41°28'	58°19'
48	27-01-2018	41°	58°23'
49	27-01-2018	40°59’	58°23’
50	27-01-2018	40°30’	58°20’
51	29-01-2018	39°59’	57°30’

Underway CTD (UCTD)

The UCTD is a new art of ocean measurement technique, provides high quality temperature and salinity data as a function of depth from a moving vessel. This instrument was extensively used in this expedition to collect high resolution (30 miles) CTD data in the upper water column along the entire ship track. The system consists of a probe assembly, winch, rewinder, davit and power supply. The probe assembly consists of a CTD instrument and a tail spool. The probe samples conductivity, temperature and depth at a sampling rate of 16 Hz while descending through the water column. Around 117 vertical profiles were collected along the ship track using UCTD. The vertical profile of temperature and salinity collected from SSTF is shown in Figure 2.

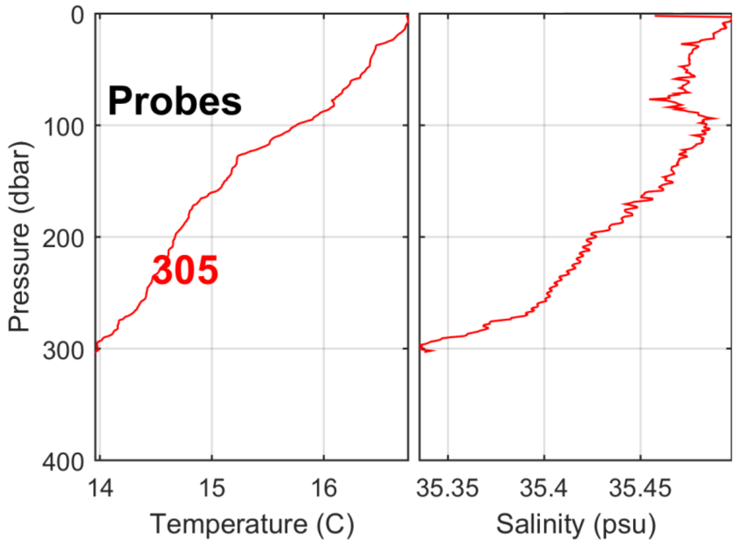

Figure 2. Vertical profile of temp and salinity

Table 3: UCTD deployment location

Sl no	Date	Time	UCTD	Latitude	Longitude
	17/12/2017	19:50 20:01 23:36	Cast 1 Cast 2 Cast 3	40°33.2429'S 40°33.2429'S 41°00.0173'S	58°46.6847'E 58°46.6847'E 59°05.5073'E
	18/12/2017	03:40 07:20 07:35 11:21 11:35 15:47 16:00 20:08 20:22	Cast 1 Cast 2 Cast 3 Cast 4 Cast 5 Cast 6 Cast 7 Cast 8 Cast 9	41°31.5000'S 42°00.3284'S 42°00.3284'S 42°30S 42°30S 43°00.0050'S 43°00.0050'S 43°30.0990'S 43°30.0990'S	59°29.2764'E 59°52.2730'E 59°52.2730'E 60°14.65'E 60°14.65'E 60°35.0162'E 60°35.0162'E 60°55.9765'E 60°55.9765'E
	19/12/2017	01:57 02:11 06:04 10:07 10:42 13:34 16:48 17:04 17:15 17:28	Cast 1 Cast 2 Cast 3 Cast 4 Cast 5 Cast 6 Cast 7 Cast 8 Cast 9 Cast 10	44°00'S 44°00'S 44°30'S 45°00.0690'S 45°03.9121'S 45°30.5600'S 46°00.89'S 46°03.2473'S 46°04.9973'S 46°06.9075'S	61°19.10'E 61°19.10'E 61°41.65'E 62°05.0922'E 62°10.3212'E 62°29.4114'E 62°52.53'E 62°54.5676'E 62°56.1669'E 62°57.9625'E
	21/12/2017	18:02 21:07 23:33	Cast 1 Cast 2 Cast 3	51°00.6646'S 51°20.8936'S 51°40.1900'S	63°21.0505'E 63°32.0274'E 63°51.2100'E

	22/12/2017	06:34 11:40 17:35 22:37	Cast 1 Cast 2 Cast 3 Cast 4	52^{o}42.1264’S 52^{o}00.0563’S 53^{o}30.7125’S 54^{o}00.0107’S	64^{o}53.4008’E 65^{o}21.8714’E 66^{o}43.2593’E 68^{o}01.5013’E
	25/12/2017	19:48	Cast 1	58^{o}30.9858’S	70^{o}16.1074’E
	26/12/2017	05:49 11:05 15:24 20:34	Cast 1 Cast 2 Cast 3 Cast 4	59^{o}00.8820’S 59^{o}30’S 60^{o}00.07’S 60^{o}30S	70^{o}07.1916’E 70^{o}49’E 70^{o}41.83’E 70^{o}21’E
	27/12/2017	00:09 03:30 07:29 11:02	Cast 1 Cast 2 Cast 3 Cast 4	61^{o}00S 61^{o}30S 62^{o}00S 62^{o}30.5647’S	70^{o}09’E 70^{o}58’E 70^{o}42’E 70^{o}07.9154’E
	28/12/2017	03:02 06:10 09:41 13:32 16:42 20:34	Cast 1 Cast 2 Cast 3 Cast 4 Cast 5 Cast 6	62^{o}59.74’S 63^{o}30.42’S 64^{o}00.27’S 64^{o}30.3169’S 65^{o}00.6132’S 65^{o}30.2237’S	70^{o}00.27’E 70^{o}19.15’E 70^{o}35.72’E 70^{o}59.7159’E 71^{o}33.2261’E 72^{o}12.5301’E
	04/01/2018	00:47 11:29 22:10	Cast 1 Cast 2 Cast 3	66^{o}34.5574’S 66^{o}32.8326’S 66^{o}32.879’S	76^{o}26.8868’E 76^{o}26.2468’E 76^{o}20.5830’E
	05/01/2018	11:45 23:04	Cast 1 Cast 2	66^{o}36.8973’S 66^{o}41.089’S	76^{o}07.9737’E 76^{o}13.9194’E
	06/01/2018	15:04	Cast 1	66^{o}37.4458’S	76^{o}14.4800’E
	08/01/2018	16:55	Cast 1	65^{o}29.3433’S	70^{o}57.8738’E
	09/01/2018	15:30	Cast 1	65^{o}30S	69^{o}05E
	10/01/2018	12:40	Cast 1	65^{o}29.4473’S	67^{o}01.9230’E
	11/01/2018	13:32	Cast 1	65^{o}30’S	64^{o}57’E
	12/01/2018	14:50	Cast 1	65^{o}26’S	62^{o}55’E
	13/01/2018	12:47	Cast 1	63^{o}28’S	61^{o}01’E

	15/01/2018	17:30 21:56 23:28	Cast 1 Cast 2 Cast 3	65°29.2998’S 65°13.5613’S 65°S	57°50.3906’E 57°45.8528’E 57°41’E
	16/01/2018	02:45 15:54 19:16 21:12 23:23	Cast 1 Cast 2 Cast 3 Cast 4 Cast 5	64°30.7308’S 63°59’S 64°45.0647’S 63°29.9662’S 63°15.3727’S	57°31.1175’E 57°26’E 57°27.7766’E 57°29.9051’E 57°31.7097’E
	17/01/2018	06:19 08:19 20:41	Cast 1 Cast 2 Cast 3	62°30’S 62°14’S 61°44.0904’S	57°30’E 57°30’E 57°11.7455’E
	18/01/2018	23:56	Cast 1	61°00.0945’S	57°37.7311’E
	19/01/2018	08:50 15:14	Cast 1 Cast 2	61°29.6375’S 59°59.6041’S	57°00.1733’E 67°08.0646’E
	20/01/2018	10:15 16:10 21:14	Cast 1 Cast 2 Cast 3	59°00.0970’S 58°45.6220’S 58°30.1411’S	55°00.7668’E 54°35.1009’E 56°09.8003’E
	21/01/2018		Cast 1 Cast 2 Cast 3	58°16.5020’S 57°26.9764’S 57°00.3675’S	57°09.5167’E 57°31.4208’E 57°30.8024’E
	22/01/2018	02:37 06:09 13:10 17:15 21:15	Cast 1 Cast 2 Cast 3 Cast 4 Cast 5 Cast 6	56°28.1729’S 55°58.6375’S 55°30.0891’S 54°59.4072’S 54°30.3496’S 53°59.8644’S	57°33.5121’E 57°30.0450’E 57°33.2462’E 57°34.0304’E 57°20.9479’E 57°13.6168 ’E
	23/01/2018	01:46 07:36 10:30 16:05 21:15	Cast 1 Cast 2 Cast 3 Cast 4 Cast 5	53°29.2020’S 52°50.8947’S 52°30.8486’S 51°59.4227’S 51°30.9757’S	57°33.9214’E 57°27.0154’E 57°10.5611’E 56°30.0528’E 56°32.8443’E
	24/01/2018	14:22 18:57 21:38	Cast 1 Cast 2 Cast 3	51°S 50°30’S 50°02.0580’S	57°30’E 57°51’E 57°43.7610’E
	25/01/2018	12:48 03:57 07:03 10:40	Cast 1 Cast 2 Cast 3 Cast 4	49°30.5421’S 48°59.4430’S 48°29.3753’S 47°57.4131’S	57°30.5361’E 57°29.5441’E 57°29.7048’E 57°30.0864’E

	26/01/2018	02:20	Cast 1	47°28’S	57°30’E
		05:15	Cast 2	47°S	57°33’E
		08:15	Cast 3	46°29.9942’S	57°38.5526’E
		11:15	Cast 4	46°S	57°42’E
		14:27	Cast 5	45°29.1657’S	57°48.0274’E
		17:13	Cast 6	44°59.8764’S	57°52.4419’E
		20:08	Cast 7	44°30’S	57°54’E
		22:58	Cast 8	44°S	57°59’E
	27/01/2018	02:18	Cast 1	43°30’S	58E
		05:28	Cast 2	43°S	58°07’E
		08:47	Cast 3	42°29.6223’S	57°11.8329’E
		11:49	Cast 4	42°00.2955’S	58°15.5055’E
		14:51	Cast 5	41°30.7250’S	58°19.0576’E
		17:40	Cast 6	41°01.5066’S	58°23.2444’E
		20:17	Cast 7	40°30’S	58°20’E
	28/01/2018	12:10	Cast 1	39°56.4395’S	58°19.8820’E
	30/01/2018	04:45	Cast 1	39°54.2214’S	57°30.4203’E
		06:59	Cast 2	39°30.0487’S	57°31.0242’E
		09:36	Cast 3	39°00.3302’S	57°32.9019’E
		11:56	Cast 4	38°31.1712’S	57°34.1126’E
		15:06	Cast 5	38°00.9277’S	57°36.1497’E
		18:06	Cast 6	37°30.4820’S	57°38.0093’E
		21:08	Cast 7	37°00’S	57°39.3720’E
		23:57	Cast 8	37°30’S	57°40’E
	31/01/2018	02:48	Cast 1	36°00’S	57°43.2258’E
		04:47	Cast 2	35°30’S	57°44.1811’E
		08:41	Cast 3	35°00.5995’S	57°45.6733’E

Direct velocity measurements using a Lowered Acoustic Doppler Current Profiler (ADCP)

A 150 KHz LADCP was used to direct velocity measurements in the PB and IOSO. It was mounted on the inner side of the CTD rosette, about 1 inch above the bottom of the frame. An additional battery with a separate battery was also mounted in the frame (Figure 3). Commands were uploaded from a file for deployment. The profiler was programmed to sample in a 1 ping burst every 1.18 seconds. Other relevant setup parameters were 8m blank, bandwidth parameter WB, water mode, and ambiguity velocity of 175 cm s^{-1}. Data was downloaded after each deployment of the LADCP using laptop running windows OS. The LADCP was operated at most of the stations where the CTD was operated (Table. 3). Further detailed processing is required to get the ocean current profile from these locations.

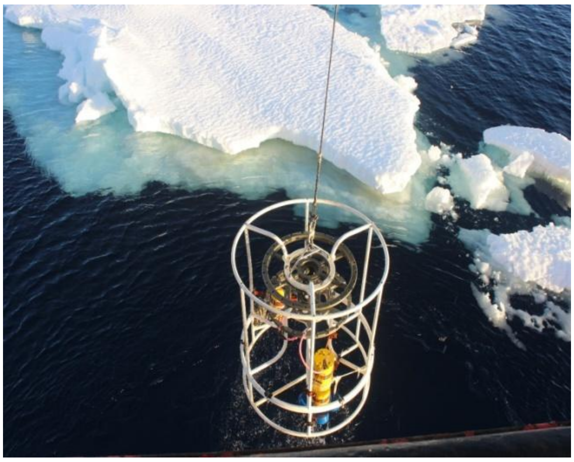

Figure 3. LADCP fixed with a CTD rosette

Mixing and Turbulence using microstructure profiler

Mixing measurements were carried out by deploying a MSS90L microstructure profiler (make: Sun and Sand Technology, Germany). The MSS90L microstructure profiler is a loosely tethered system, comprising two PNS06 shear probes, one higher solution temperature and conductivity sensor and onset of standard CTD sensor (Figure 4). The PNS06 shear probes are air-foil type micro scale velocity fluctuation sensor and the main housing of the profiler consists of a cylindrical stain less tube with length of 1.25 m and diameter of 106m.All sensors are sample data rate of 1024Hz, and the data is transmitted to SDA ship board. The microstructure profiler was operated from the star board side and the ship was allowed to drift during the time of measurement. The instrument was operated in all the CTD stations up to a maximum depth of 250m and the data on vertical shear in horizontal velocities, temperature and salinity were recorded. Based on the Reynolds averaged turbulence kinetic energy equation, the turbulent kinetic energy dissipation rate can be calculated from this area.

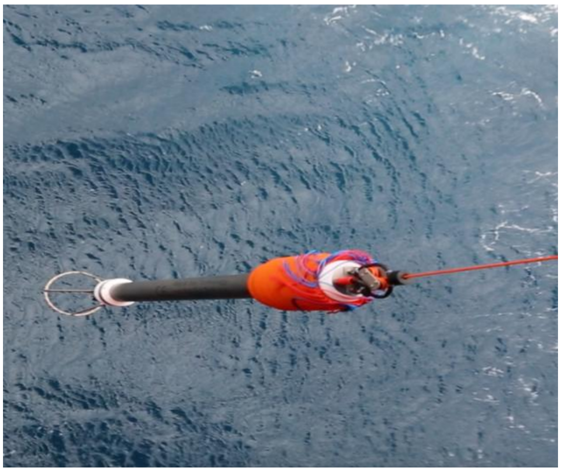

Figure 4. Microstructure profiler operation in the expedition

ARGO Deployment

As part of the National Argo data programme 7 floats were provided by INCOIS, Hyderabad to be deployed along the cruise track at pre decided locations (Table 2). These 7 Argo floats also included 2 ice floats. All the floats have been deployed successfully (Figure 5). The meta-data form after deployment of each float was prepared and sent to INCOIS for further procedure.

Figure 5. Deployment of ARGO float

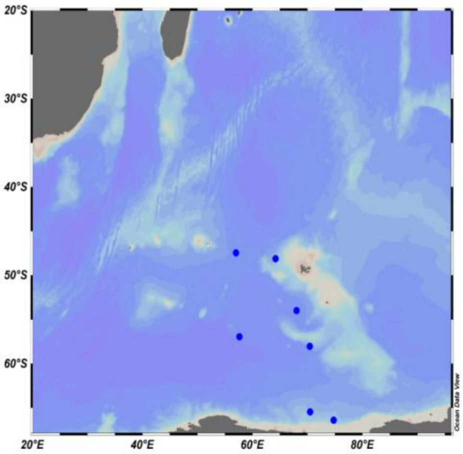

Figure 6. Locations where ARGO floats were deployed

Table 4. Argo deployment location

Sr. No.	Float ID	Model Name	Deployed		DEPLOYED ON (Date & Time in UTC)
			LATITUDE	LONGITUDE	
1	AL2500-17IN001	NKE-ARVOR-I	48° 07.6738' S	64° 12.1043' S	20-12-2017, 12:37 hrs
2	AL2500-17IN002	NKE-ARVOR-I	54°S	68° 02' E	23-12-2017 12:37 hrs

3	AL2500-17IN003	NKE-ARVOR-I	58° 02.4610' S	70° 26.5358' E	25-12-2017 12:32 hrs
4	AL2500-17IN004	NKE-ARVOR-I	56° 58.7977' S	57° 38.4011' E	21-01-2018 18:51 hrs
5	AL2500-17IN005	NKE-ARVOR-I	47° 28.7067' S	57° 0.9949' E	25-01-2017 22:16 hrs
6	AI2600-17IN009	NKE-ARVOR-I	65° 28.4473' S	70° 50.8333' E	08-01-2018 13:17 hrs
7	AI2600-17IN0010	NKE-ARVOR-I	66° 25.2447' S	74° 46.0773' E	29-12-2017 :03 hrs

2. Expected Outcome

The Prydz Bay (PB) plays a major role in the SO circulation and formation of deep and intermediate water masses. The collected high resolution hydrographic data along with 9th SOE would be helpful to understand the PB hydrodynamics as well as its connection to the Indian sector of SO. Also, the full depth hydrogrpahic profiles collected along 57°30′E during the survey will be useful to understand the recent rapid freshening of the deep and intermediate water masses in the IOSO.

References

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- Katsumata, K., H. Nakano., Kumamoto, Y., 2014. Dissolved oxygen change and freshening of Antarctic Bottom water along 62◦S in the Australian-Antarctic Basin between 1995/1996 and 2012/2013, Deep Sea Research II, 114, 27-38.

5.2 Southern Ocean Carbon and Climate observations and Modeling

Introduction

With its unique circulation, where old waters rich of carbon and nutrients are up welled, and young and dense waters are formed [e.g., Marshall and Speer, 2012; Morrison et al., 2015; Talley 2013], the Southern Ocean represents a key player in the global climate system. Of the total anthropogenic carbon globally absorbed per year, the Southern Ocean contributes half of its uptake [e.g., Takahashi et al., 2012]. However, the uncertainties associated with the carbon system are large [e.g., Mikaloff Fletcher et al., 2006]. The limited number of in-situ measurements and the lack of wintertime and under sea ice observations are one of the biggest gaps for understanding the Southern Ocean's role in the climate and carbon systems. Reducing these uncertainties by increasing the data coverage is, therefore, extremely important. Especially, given the large spatial and temporal variability of dissolved carbon concentration [e.g. Rosso et al., 2017] and air sea CO_2 flux [e.g., Takahashi et al., 2009; Resplandy et al., 2014], an observing system able to inform on the carbon parameters at different space and time scales is required.

The Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) is increasing the spatial and temporal coverage of physical and biogeochemical parameters in the Southern Ocean, by deploying a fleet of autonomous profiling floats equipped with temperature, salinity, depth, pH, nitrate, oxygen, fluorescence and backscatter sensors. With a predicted lifetime of 5 to 7 years, the floats are informing about seasonal cycles of biogeochemical parameters, their inter annual variability, wintertime and under ice processes, as most of the SOCCOM floats are also enabled to profile under sea ice, store the data and surface to report profiles after ice melts.

SOCCOM is a project supported by the National Science Foundation, under the US NSF award PLR-1425989, and is housed at Princeton University (NJ). It brings together a number of scientists with a physical, biological and chemical oceanographic expertise, from different institutes across the United States. To reach its goal, SOCCOM is building up to 200 floats by 2020, and, at present, it has already about 95floats in its fleet.A large part of the SOCCOM efforts is also directed toward modeling of biogeochemical cycles, with a focus on model improvement, comparison and better simulation of biogeochemical parameters, using climate models and state estimates [e.g. Verdy and Mazloff, 2017; Rosso et al., 2017].Together with observational and modeling objectives, a fundamental effort of the SOCCOM project is also invested in outreaching, in order to build a strong line of scientific communication with the general public, and to educate middle and high school students. ``Adopt-a-float'' is one of the programs SOCCOM is promoting, which aims to engage students with scientific research.

An overview about SOCCOM, its new developments, outcomes, data from the profiling floats, and the details about the different working teams associated with the project can be found on the website http://soccom.princeton.edu.

Objectives

In order to increase the spatial and temporal coverage of biogeochemical and physical measurements in the Southern Ocean, it is imperative to understand the gaps in observations, in order to select regions where to deploy the floats. The south Indian Ocean is one of the regions of the Southern Ocean where biogeochemical observations are lacking most. The objective of SOCCOM on the SOE-10, 2017-18 expedition was therefore to deploy a series of profiling floats, in order to cover the different regimes in the Indian Ocean: Subtropical, Subantarctic, Polar, and Antarctic frontal zones. Seven profiling floats were planned to be deployed: Figure 7 shows the initial plan for the location of their deployment.

Materials and Methods

Seven biogeochemical profiling floats have been deployed, as part of the SOCCOM project, two of which had been built by Seabird ('Navis floats'), while the remaining by the University of Washington Float Lab, from components purchased from Teledyne/Webb ('Apex floats') (Figure 7). All the floats were equipped with a CTD (conductivity-temperature-depth), oxygen, nitrate, pH, optical fluorescence and backscatter sensors, and ice-avoidance software. The floats are programmed to descend and drift at 1000 m for 10 days, then sink to 2000 m after which they resurface profiling through the full 2000 m depth. Data acquisition is made through Iridium Satellite communication and GPS. The list of the SOCCOM floats, with their identification number is provided in Table 5.

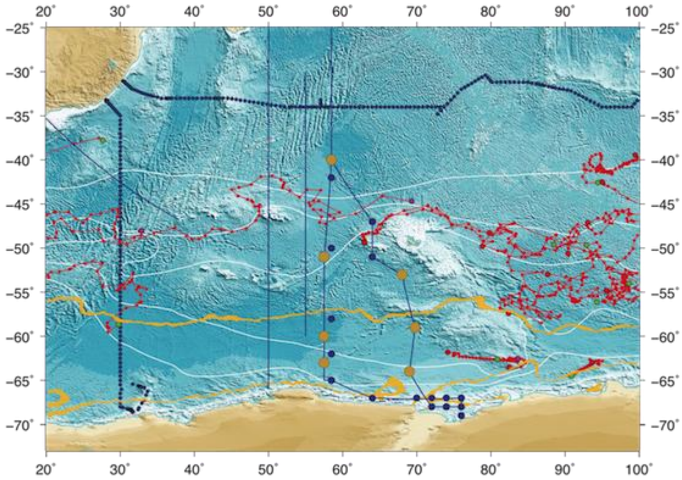

Figure 7. Indian Ocean bathymetry. The blue line shows the preliminary SOE-10 cruise track, blue dots are the SOE-10 preliminary stations and in orange are the SOCCOM proposed locations. On the map, the winter and summer sea ice extent are shown in orange. Red dots are existing Argo floats. Black dots and thin blue lines (west of the SOE-10 track) are possible future cruise tracks, which SOCCOM will be joining.

In order to provide quality control and validation for the first depth profile of the floats, a CTD cast down to 2000 m was required. On the CTD rosette, an additional fluorometer and backscatter sensor (FLBB)was mounted, for this purpose. Furthermore, samples of waters for depths down to 2000 m were required, when possible, for pH, nutrients, POC and HPLC measurements. Winkler oxygen measurements are also an essential part for the quality control and validation process: such measurements were taken by NCAOR personnel, and will not be discussed in this report. Table 5 shows the number of samples that were collected at the different stations/casts, prior the deployment of each float

Table 5. Water samples drawn at the floats' deployment location

Sl N0.	**Float No.**	**St./cast**	**Parameter**	**Depths**	**No. samples**
1	Navis 0690	01/01	pH	500 m to 2000 m	5
		01/01	nutrients	500 m to 2000 m	5
		01/04	pH	0 m to 200 m	9 (8 + duplicate)
			nutrients	0 m to 200 m	8
2	Apex 12734	03/01	pH	0 m to 1500 m	5 (4 + duplicate)
		03/01	nutrients	0 m to 1500 m	4
		bucket	nutrients	surface	1

		bucket	HPLC	surface	2
		bucket	POC	surface	2
3	Navis 0693	05/01	pH	0 m to 1400 m	13 (12 + dupl)
		05/01	nutrients	0 m to 1400 m	12
		05/01	HPLC	Surface + DCM	2
		05/01	POC	Surface + DCM	2
4	Apex 12755	06/01	pH	500 m to 2000 m	5 (4 + duplicate)
		06/01	nutrients	500 m to 2000 m	4
		06/04	pH	0 m to 200 m	9
		06/04	nutrients	0 m to 200 m	9
		06/05	HPLC	Surface + DCM	2
		06/05	POC	Surface + DCM	2
5	Apex 12730	31/01	pH	500 m to 2000 m	5 (4 + duplicate)
		31/01	nutrients	500 m to 2000 m	4
		31/04	pH	0 m to 200 m	9
		31/04	nutrients	0 m to 200 m	9
		31/05	HPLC	Surface + DCM	2
		31/05	POC	Surface + DCM	2
6	Apex 12781	33/01	pH	500 m to 2000 m	5 (4 + duplicate)
		33/01	nutrients	500 m to 2000 m	4
		33/04	pH	0 m to 200 m	9
		33/04	nutrients	0 m to 200 m	9
		33/05	HPLC	DCM	1
		33/05	POC	DCM	1
		33/06	HPLC	Surface	1
		33/06	POC	Surface	1
7	Apex 12757	34/01	pH	500 m to 2000 m	5 (4 + duplicate)
		34/01	nutrients	500 m to 2000 m	4
		34/04	pH	0 m to 200 m	9
		34/04	nutrients	0 m to 200 m	9
		34/06	HPLC	Surface + DCM	2
		34/06	POC	Surface + DCM	2

Nutrients samples (30 ml each) has been stored at -20°C, and will be shipped frozen back to Scripps Institution of Oceanography (SIO), where they will be analyzed by the Shipboard

Technical Support/ODF lab. pH samples (bottles of 0.5 l) will be shipped (not frozen) to SIO, where they will be analyzed by Andrew Dickson's lab. HPLC/POC samples have been first filtered, and then stored in liquid nitrogen, and will then be shipped back to SIO in a dry shipper container, to preserve the low temperature. HPLC samples will be processed at NASA GSFC and POC samples will be processed at University of California Santa Barbara; SOCCOM is responsible for the data set.

The floats have been deployed at the conclusion of all the other scientific operations, departing from the station and while the ship was steaming at ~1 knot. The deployment occurred at the ship's aft, using a line strung to the float (or to the cardboard box, if present), with one end of the line tied to a cleat and the other held by the technician. No issues were encountered during their deployment. Each of these floats was self-activating, so no initial operations were required before their deployment to activate them.

Preliminary results

The location and time of deployment for the seven floats are listed in Table 6. All the floats have provided the first test profile after 1 day of cycle, which showed good performance of each sensor (Figure 8) shows an example of property/depth profiles for the float #0690). Initial profiles are quality controlled using data from the CTD casts, both from the sensors mounted on the rosette (CTD and FLBB), and from water samples (oxygen and salinity from NCAOR; pH, nitrate and HPLC/POC from SIO).

Table 6. Locations, date and time of floats' deployment

No.	Float ID	Latitude	Longitude	Date (UTC)
1	Navis 0690	40° 02.42' S	57° 37.23' E	15/12/2017 at 16:39
2	Apex 12734	54° 02.11' S	68° 02.63' E	23/12/2017 at 13:19
3	Navis 0693	58° 59.75' S	70° 01.52' E	26/12/2017 at 02:58
4	Apex 12755	63° 00.33' S	69° 58.34' E	27/12/2017 at 22:27
5	Apex 12730	63° 59.22' S	57° 24.33' E	16/01/2018 at 13:17
6	Apex 12781	56° 58.83' S	57° 39.08' E	21/01/2018 at 18:59
7	Apex 12757	51° 00.78' S	57° 32.41' E	24/01/2018 at 11:32

All the floats have been performing well in their following 10-day cycles, except for the two Navis floats. Float #0690, in fact, showed a malfunction in the pH sensor almost immediately after the first test cycle. Furthermore, the CTD on the float #0693 stopped working after two cycles. Prior the deployment of this last one, some grease was noticed at the base of the bolts on the top of the float. Immediate discussion was carried on with lead float engineer Dana Swift at UW, part of the SOCCOM project. After careful visual analysis, it was decided that the grease was not a sign of a malfunction, but it was due rather to an exaggerated use of silicone to seal the float. However, following the failure of the CTD on such float, after days in the water, more investigation will be carried on, together with Seabird Navis.

Expected outcome

Data visualization is available at http://soccom.princeton.edu/soccomviz.phpusing the SOCCOMViz platform. Also, data (both QC and noQC) are publicly accessible and usable for any scientific study from the first acquired profile, using a FTP platform through the website http://soccom.princeton.edu/content/float-data-ftp-access.

As part of the ``Adopt-a-Float'' program, students from 5 different schools in the US have followed the journey of the expedition through the blog that Dr. Isabella Rosso (SOCCOM personnel present during the SOE-10 cruise) hasupdated along the cruise (http://soccomatsea.blogspot.com), and have been learning about the Southern Ocean waters, by discussing with their school teacher, and plotting data using the graphical SOCCOMViz platform. It is a success to see many young students excited about science, engaged with research and passionate about understanding our oceans.

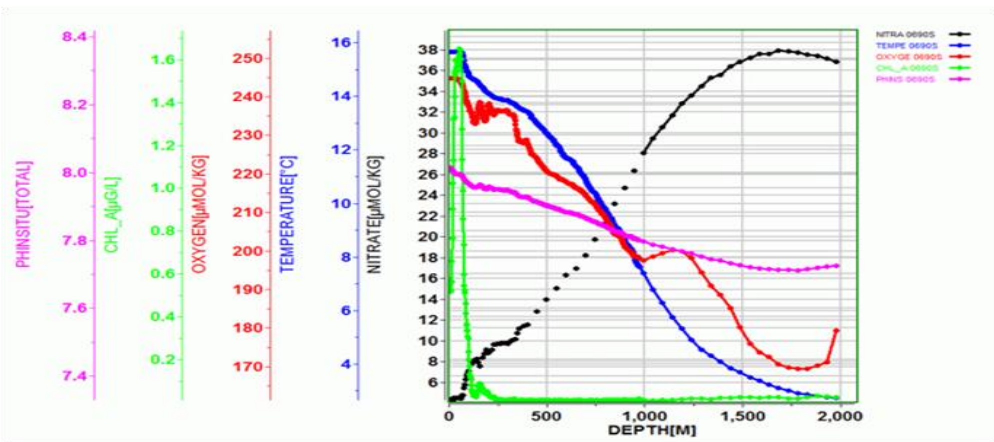

Figure 8. Property/depth profiles for the float Navis #0690: pH in magenta, chlorophyll a (green), oxygen (red), temperature (blue), and nitrate (black).

The data that the floats will be collecting for the next 5 to 7 years will provide a source to study seasonal cycles of biogeochemical parameters in an area that has been historically poorly sampled, and help to understand the variability of carbon fluxes and cycle. From the trajectories of the floats, much can be learned about pathways of waters at 1000 m in this area. Data will also be used to inform state estimate models, such as the Biogeochemical Southern Ocean State Estimate (BSOSE; Verdy and Mazloff, 2017), which by acquiring every available observation and by reducing the misfit between model solution and observations, it aims to provide a more realistic simulation of the biogeochemical and physical properties of the Southern Ocean.

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5.3 In-situ and satellite optical characterization of Southern Ocean waters to understand phytoplankton functional types and ecosystem functioning

Introduction

Ocean colour remote sensing provides information about the global oceans including the polar seas, including the Arctic seas and Antarctica. Though the upper ocean optical properties of these two oceans are different, the contribution of the ocean biological variability / productivity plays an important role in studying the global bio-geo-chemical cycles. Spectral characteristics of water column are modified by dissolved and suspended substances when light penetrates into it. It has become increasingly important to classify optical water types and define optical properties. Jerlov (1968) originally used attenuation coefficients to characterize different water bodies into five optical water types. Smith and Baker (1978) introduced the concept of bio-optical state to relate the total effect of biological processes on the optical properties of natural waters. Satellite measurements of ocean colour (Mc Clain, 2009) are primary tools for assessing ocean productivity and its response to climate change (Behrenfeld*et al.*,2006). Improving the accuracy of the ocean colour algorithms is therefore a high priority. Chlorophyll concentrations in the Southern Ocean are typically quite low despite high concentrations of the major nutrients such as nitrate and phosphate in the surface waters (Moore and Abbott, 2000). The Southern Ocean is thus the largest of the High-Nutrient, Low-Chlorophyll (HNLC) region (Martin, 1990) of the global oceans. Phytoplankton Functional Types (PFTs) on the other hand are conceptual groupings of phytoplankton species, which have an ecological functionality in common (either in terms of the food web or biogeochemical cycles). Examples include nitrogen fixers (e.g.*Trichodesmium*), calcifiers (coccolithophores), DMS producers (e.g.,*Phaeocystis*) and silicifiers (e.g., diatoms).PFTs can be derived from ocean-colour remote sensing both through direct effects (e.g. changes in phytoplankton composition can lead to changes in absorption and backscattering coefficients, affecting the reflectance spectra) as well as indirect effects (e.g. changes in phytoplankton composition is accompanied by changes in the ensemble of particles and dissolved substances, leading to changes in the reflectance spectra).

In order to understand the optical characterization of Southern Ocean waters to understand phytoplankton functional types (PFTs), some of the objectives of the project are addressed during this expedition.

Objectives

1. To study the bio-optical variability in the different fronts of Southern Ocean (SO) and Antarctic Coast including phytoplankton pigments.
2. Estimation and assessment of inherent and apparent optical properties in SO and Antarctic Coast.
3. Measurement of Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}) of phytoplankton, estimation of GPP (Gross Primary Production) in Southern Ocean and Construction FLC (Fluorescent Light Curve) of phytoplankton in polar fronts using Fast Repetition Rate Flurometer (FRRF).
4. To measure background concentrations of Green House Gases (CO_2, CH_4& H_2O), size segregated Aerosol concentrations corresponding to PM1, PM2.5, and PM10, Aerosol optical depth, columnar water vapour and columnar ozone in Southern Ocean and Antarctic Coast.
5. Measurement of Precipitation and related parameters using MicroWave Rain Radar.

Methodology/ work carried out onboard

The NRSC team operated oceanographic and atmospheric instruments during Southern Ocean Expedition (SOE-10) cruise on board *S.A. Agulhas*for better understanding of bio-optical variabilities, primary productivity, greenhouse gases, surface aerosol concentrations, columnar measurements of aerosol, water vapor, ozone and precipitation in southern ocean and coastal Antarctica. The data were collected from 09th Dec, 2017 to 31st Jan, 2018 and covering different frontal regions of Southern Ocean and Antarctica coast. Subsequently one time series observation also carried out at fixed location (66° 30’S, 76°30’E) from 3rd to 6th Jan, 2018.

We have operated Inherent Optical Profiler (IOP) and Hyper Spectral Radiometer to study the bio-optical properties of water column in collaboration with Dr. S.C. Tripathy, Senior Scientist, NCAOR, Goa. The instruments details and parameters obtained are provided below.

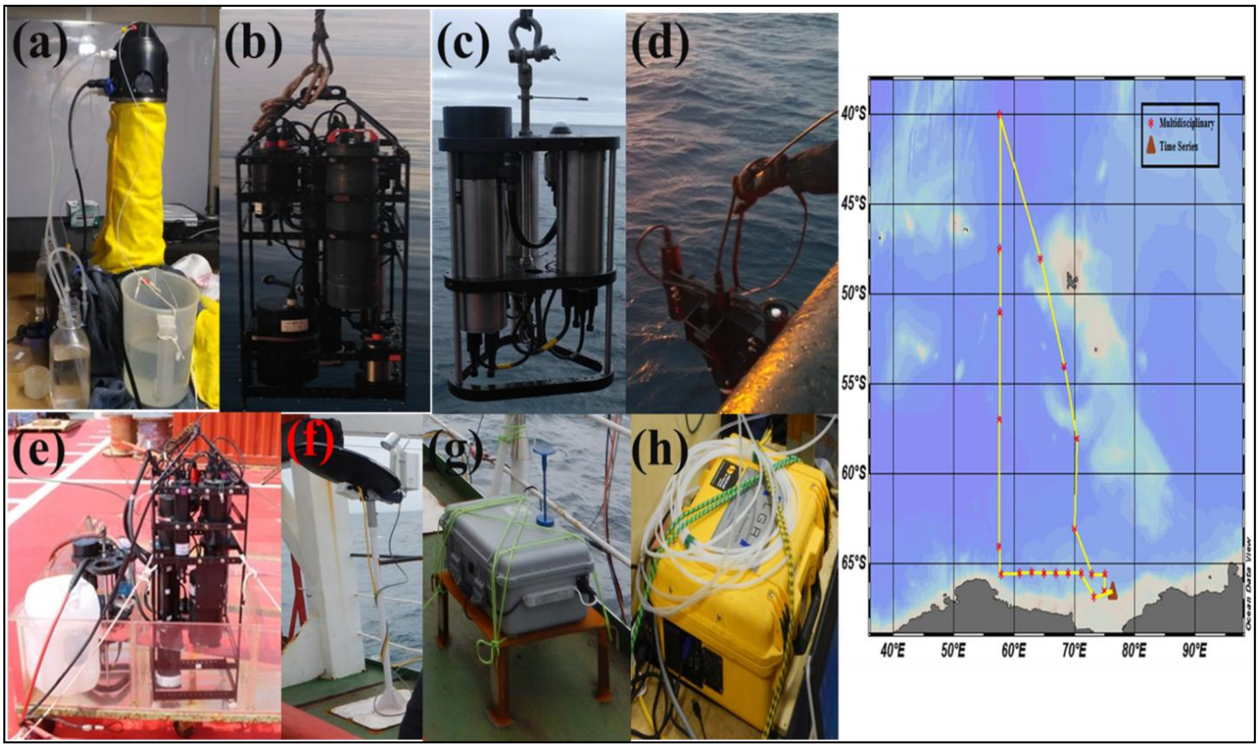

Figure 9: (a) Fast Act Lab System; (b) IOP, (c) FRRF, & (d) Radiometer in profiling mode; (e) IOP & FRRF in surface mapping mode; (f) MicroWave Rain Radar; (g) Dust Track Monitor; (h) Greenhouse Gas Analyzer; and a cruise track map with stations for SOE-10.

Inherent Optical Profiler

Inherent Optical profiler (IOP) provides inherent optical properties like absorption and attenuation coefficients of water column at 88 wavelength bands from 400nm to 736nm along with parameters like Photosynthetically Active Radiation (PAR), chlorophyll & Color Dissolved Organic Matter (CDOM) fluorescence, and Backscattering coefficients at 9 bands from 400nm to 720nm, Salinity, temperature with depth. IOP was operated in profiling mode for water column understanding and surface mapping mode for surface measurement along the ship track and sampling locations are provided in Table 10 for profiling mode and Table 11 for surface mapping mode.

Hyper-Spectral Radiometer

Hyper-Spectral Radiometer provides apparent optical properties of water column like underwater light fields, water leaving radiances, remote sensing reflectance at every wavelength from 354nm to 800nm along with chlorophyll fluorescence, surface Irradiances, and Salinity, Temperature with depth. Hyper-Spectral Radiometer was operated in profiling mode for water column understanding and sampling locations are provided in Table 10.

Fast Repetition Rate Flurometer (FRRF)

Fast Repetition Rate Flurometer (FRRF) provides physiological properties of phytoplankton like Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}), Reaction Center concentration [RCII] along with Photosynthetically Active Radiation (PAR) with depth information under sun illumination conditions. Using these parameters we can estimate GPP (Gross Primary Production).Fast Repetition Rate Flurometer (FRRF) was operatedin profiling mode for water column understanding and surface mapping mode for surface measurement along the ship track. Sampling location is provided in Table 8 for profiling mode and Table 9 for surface mapping mode.

Fast Act system (Lab based)

Fast Act system (Lab based) provides physiological properties of phytoplankton like Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}), Reaction Center concentration [RCII] under artificially produced light conditions. Using these parameters we constructed Fluorescent Light Curves (FLCs) for polar front regions for different depths. Sampling location is provided in Table 7.

Table 7. Sampling details of Fast Act (Lab based) operation for FLC construction

S.No	Station.No	Date	Lat (°S)	Lon(°E)	Depths(m)	Parameters Measured
1	33	21-01-18	56.99	57.54	0/40/70/90/120	Fluorescence Light Curves (FLCs)
2	34	24-01-18	51.00	57.53	0/20/40/70/90/120	
3	35	25-01-18	47.52	57.52	0/20/40/60/90/120	
4	36	29-01-18	40.00	57.30	0/20/40/60/90/120	

Micro Rain Radar

The Micro Rain Radar measures vertical profiles of rain rate (mm/hr), drop size distribution, fall velocity, liquid water content and radar reflectivity. This instrument operates with electromagnetic radiation at frequency of 24.23 Ghz with a modulation of 0.5-15Mhz according to the height resolution (e.g. 300m-10m). The radiation is transmitted vertically into the atmosphere where a small portion is scattered back to the antenna from rain drops or other forms of precipitation.

Table 8: The stations detail for vertical sampling of IOP, FRRF and Radiometer.

S. No.	Station Number	Date	Lat (°S)	Lon (°E)	Depth (m)	IOP	IOP measured	FRRF	FRRF measured	Radiometer	Radiometer measured
1	1	15-12-17	40.00	57.53	200	Y	Absorption , Attenuation, Backscattering coefficients, Chlorophyll Fluorescence, PAR, Temperature, Salinity, Turbidity, Depth	N	Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}), Reaction Center concentration [RCII], PAR, Temperature, and Salinity, depth	N	Upwelling Radiance, Down-welling Irradiance, Surface Irradiance, Chlorophyll, Temperature, Salinity, depth
2	2	20-12-17	48.01	64.35	300	Y		Y		N	
3	3	23-12-17	54.01	68.20	300	Y		Y		N	
4	4	25-12-17	58.02	70.31	300	Y		Y		Y	
5	6	27-12-17	63.01	69.98	300	Y		Y		Y	
6	7	30-12-17	65.53	74.96	200	Y		Y		Y	
7	9	31-12-17	65.54	72.88	200	Y		Y		Y	
8	11	01-01-18	66.82	73.26	200	Y		Y		Y	
9	13	02-01-18	66.48	74.90	200	Y		Y		Y	
10	15 TS1	03-01-18	66.60	76.43	200	Y		Y		Y	
11	15 TS2	03-01-18	66.56	76.39	200	Y		Y		Y	
12	15 TS3	04-01-18	66.54	76..43	200	Y		Y		Y	
13	15 TS4	04-01-18	66.55	76.37	200	Y		Y		Y	
14	15 TS5	05-01-18	66.58	76.20	200	Y		Y		Y	
15	15 TS6	05-01-18	66.68	76.28	200	Y		Y		Y	
16	15 TS7	06-01-18	66.63	76.29	200	Y		Y		Y	
17	17	08-01-18	65.50	70.96	200	Y		Y		Y	
18	19	09-01-18	65.51	68.96	200	Y		Y		Y	
19	21	10-01-18	65.50	67.01	200	Y		Y		Y	
20	23	11-01-18	65.50	64.98	200	Y		Y		Y	
21	25	12-01-18	65.46	62.91	200	Y		Y		Y	
22	27	13-01-18	65.50	61.00	200	Y		Y		Y	
23	30	15-01-18	65.50	57.85	200	Y		Y		Y	
24	31	16-01-18	64.00	57.45	200	Y		Y		N	
25	33	21-01-18	56.99	57.54	200	Y		Y		Y	
26	34	24-01-18	51.00	57.53	200	Y		Y		Y	
27	35	25-01-18	47.52	57.52	200	Y		Y		Y	
28	36	29-01-18	40.00	57.30	200	Y		Y		Y	
Total number of cast by each instruments						**28**		**27**		**24**	

Greenhouse Gas Analyzer

Greenhouse gas analyzer was used to measure the greenhouse gas concentrations (CO_2, CH_4 & H_2O) along the ship track. The sampling details are given in table 9.

Dust Track Monitor

Dust track monitor was operated to measure the size segregated Aerosol concentrations (corresponding to PM1, PM2.5, and PM10) along the ship track and details are given in Table 8.

Table 9: The sampling details of operated instruments in continuous mode along the track.

S. No.	Starting Location		Ending Location		Sampling frequency	Date		Total No. of Days
	Lat (°S)	Lon (°E)	Lat (°S)	Lon(°E)		Start	End	
1	**Inherent Optical Profiler (IOP)** Absorption, attenuation, backscattering coefficients, chlorophyll fluorescence, PAR							
	27^0	57.5^0	35^0	57.5^0	30 minutes	11-12-17	14-12-17	4
2	**Fast Repetition Rate Fluorometer (FRRF)** Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}), Reaction Center concentration [RCII]							
	27^0	57.5^0	35^0	57.5^0	1 minutes	11-12-17	31-01-18	51
3	**Micro Rain Radar** Rain Rate, Drop size distribution, fall velocity, liquid water content and radar reflectivity							
	27^0	57.5^0	27^0	57.5^0	30 seconds	8/12/17	4/5/2017	59
4	**Greenhouse gas Analyser** Surface concentrations of CO2, CH4 and H2O							
	27^0	57.5^0	27^0	57.5^0	One second	8/12/17	4/5/2017	59
5	**Dust track monitor** Particulate matter (PM1, PM10 and PM2.5)							
	27^0	57.5^0	27^0	57.5^0	30 minutes	8/12/17	4/5/2017	59
6	**Sunphotometer, and Ozonometer** Aerosol optical depth, Columnar Ozone and water vapor							
	27^0	57.5^0	27^0	57.5^0	30 minutes (Subjected to clear sky)	8/12/17	4/5/2017	59 (290 Observations)

Sun-photometer and Ozonometer

Sunphotometer and Ozonometer were operated to measure the aerosol optical depth, columnar Ozone and water vapour along the ship track provided to clear sky and details are given in Table 9.

Iron enrichment experiment with onboard incubation

We have conducted Iron Enrichment Experiment with onboard incubation to study the effect of iron and siderophore in enhancing the productivity in Southern Ocean, one of the largest HNLC (High Nutrient Low Chlorophyll) region in collaboration with, NCAOR, Goa. Productivity of incubated inoculum is monitored with Fast Act system. Complete procedure of incubation is produced in the report submitted.

Preliminary Results

Inherent Optical Properties measured in SO

The IOPs data were collected at 28 stations coving different fronts in southern ocean and near to Antarctic coast. The processing and corrections are required to do better analysis and possible only after SOE cruise. The processing of one cast of high bloom time series station was carried out on board to show the preliminary result as shown in Figure 10. In this figure, the deep chlorophyll maxima (DCM) is observed at ~29m depth with very high concentration of ~20µg/l and parallel to this DCM, the absorption (a), attenuation (c), backscattering (bb), and turbidity also observed maximum at this depth. The PAR profile showed that this DCM depth observed above euphotic depth (~40m).

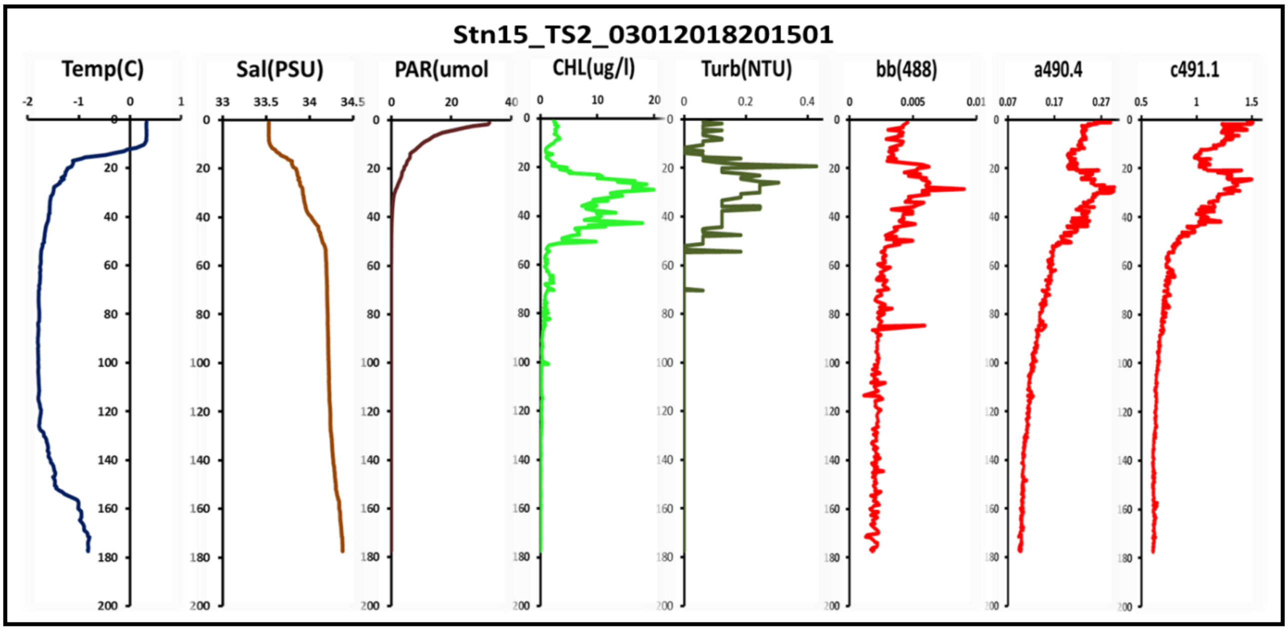

Figure 10: The vertical distributions of inherent optical properties (IOPs) over high bloom area (time -series second cast) where optimum values were observed for IOPs at ~29m below the surface.

Underwater light field measured in SO

The Hyper-spectral radiometer data were collected at 24 stations coving different fronts in southern ocean and near to Antarctic coast. The processing of one cast of high bloom time series station was carried out on board to show the preliminary result as shown in Figure 3. In this Figure, the maximum diffuse attenuation at 490nm is observed at DCM depth (~29m) which is placed above the euphotic depth.

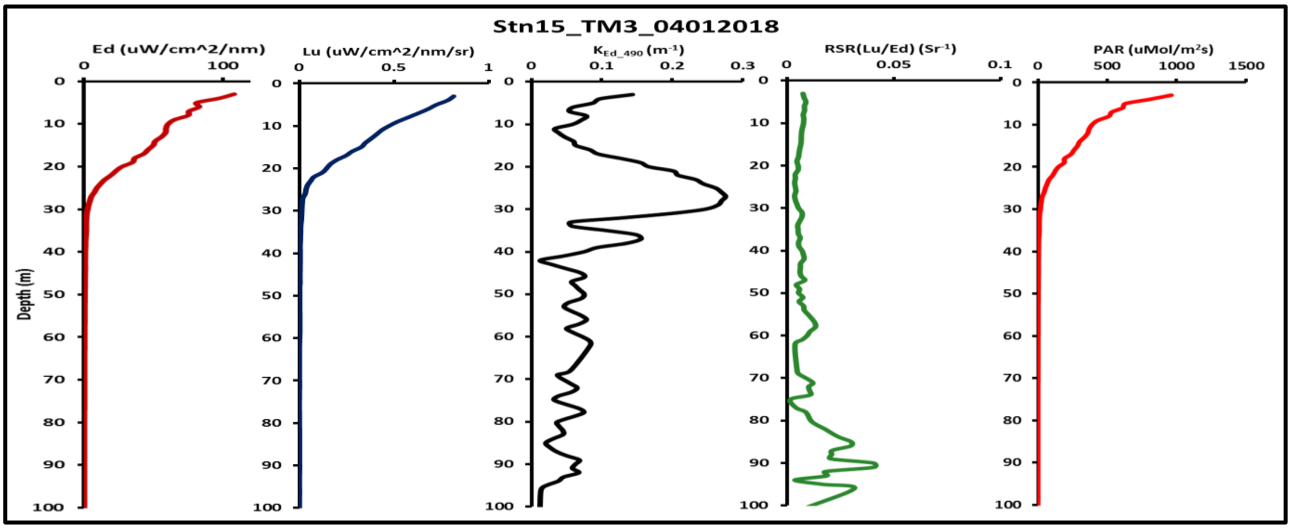

Figure 11:The vertical distributions of underwater light field over high bloom area (time series third cast) where high diffused attenuation at 490nm is observed at ~29m below the surface.

Precipitation measurements in SO:

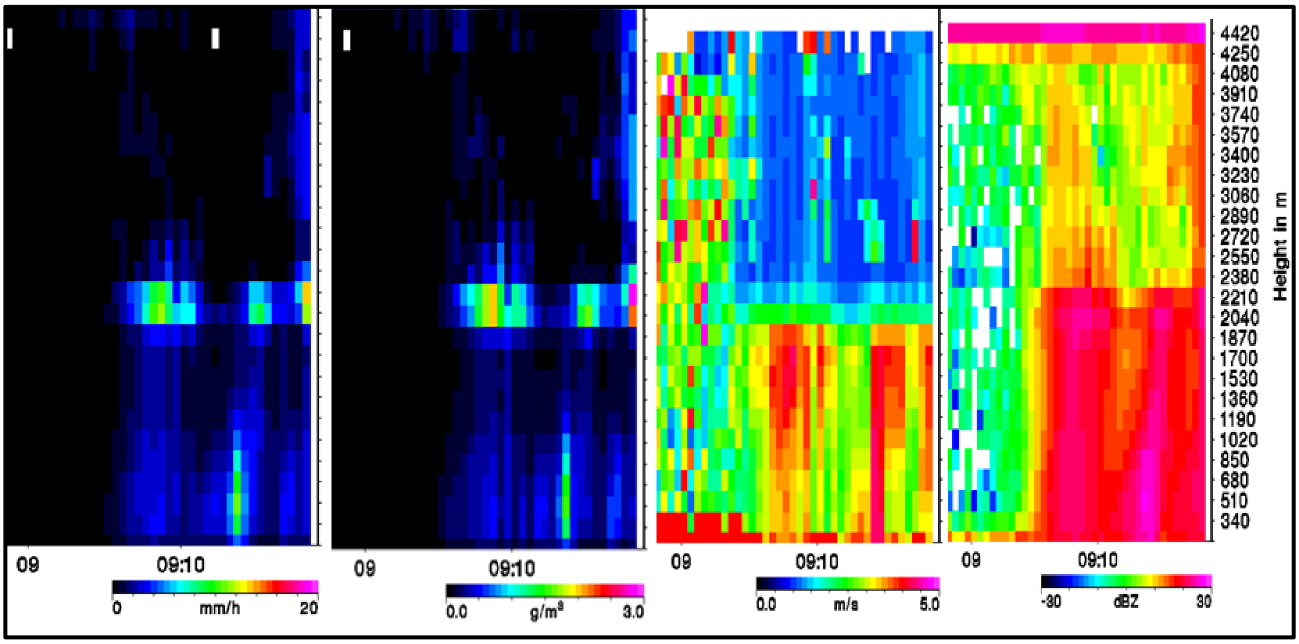

Figure 12: Rain Rate, Liquid Water Content, Fall Velocity and Radar Reflectivity from left to right.

Photosynthesis parameters in SO

Photosynthesis parameters are very important in understanding and estimating primary production in the ocean, which intern is very important in understanding the biological pump and global carbon cycle. Here we are showing profiles of Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}), two very important photosynthesis parameters observed at Time series station using Fast Repetition Rate Flurometer and Fluorescence Light Curve (FLC) constructed for Polar Fornt-1 using Fast Act (Lab System).

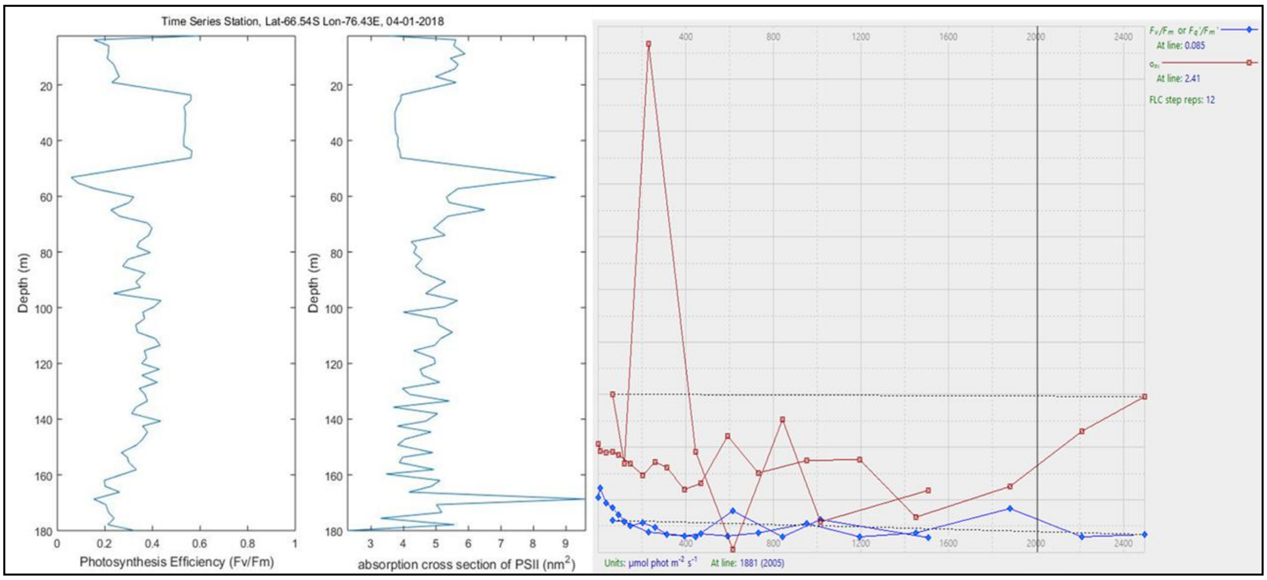

Figure 13: Vertical profiles of Photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}), Fluorescence Light Curve at Polar Front-1.

Greenhouse Gas Concentrations in SO

Greenhouse gas concentrations (CO_2, CH_4, H_20) are important to understand role of Southern Ocean (SO) in global carbon cycle and radiation budget. SO being a pristine environment provides the measure of background concentrations to study climate change. The concentrations (*uncorrected)* of CO_2, CH_4, H_20 measured by GGA on 31st Dec, 2017 (04:26 UTC) at Location near Antarctic coast (Lat. 65.5^0 Lon.72.9^0) are given in table 4.

Size segregated Aerosol concentrations in SO

Size segregated Aerosol concentrations (corresponding to PM1, PM2.5, and PM10) are important to understand the influence of continental sources or long range transport of different aerosol size fractions. The Aerosol concentrations measured by Dust track monitor on 31st Dec, 2017 (04:26 UTC) at Location near Antarctic coast (Lat. 65.5^0 Lon.72.9^0) are given in Table 10.

Measurements of Aerosol optical depth, columnar water vapor and columnar ozone in Southern Ocean

A large uncertainty exists regarding aerosols and the effect they have on the earth's radiation budget and global climate change. Atmospheric aerosols have direct and indirect impacts on the earth's radiation budget and the radiative forcing on the climate system. The distribution, concentration and types of aerosols are therefore of great importance regarding global warming and climate change. Ozone is a green house gas with long-lasting impacts on global climate change through atmospheric chemistry. AOD (at 5 wavelengths), Columnar Ozone and columnar water vapor measured on 2nd Jan 2018 (05:25 UTC) at Location near Antarctic coast (Lat. 66.5^0 Lon.74.7^0) are given in table 4. Spectral variation of AOD is shown in Figure 6.

Table 10: The output of atmospheric observations in SO.

Instruments	Date of observations	Parameters	Outputs
Green House Gas Analyzer	31st Dec, 2017	CO_2	404 PPM
		H_20	4569 PPM
		CH_4	1.77 PPM
Dust Track Monitor	31st Dec, 2017	PM1	0.002 mg/ m^3
		PM2.5	0.003 mg/ m^3
		PM10	0.003 mg/ m^3
Sunphotometer and Ozonometer	2nd Jan, 2018	AOD at 380 nm	0.067
		AOD at 440 nm	0.034
		AOD at 500 nm	0.062
		AOD at 675 nm	0.065
		AOD at 870 nm	0.032
		Columnar Ozone	309 DU
		Columnar water vapor	0.5 cm

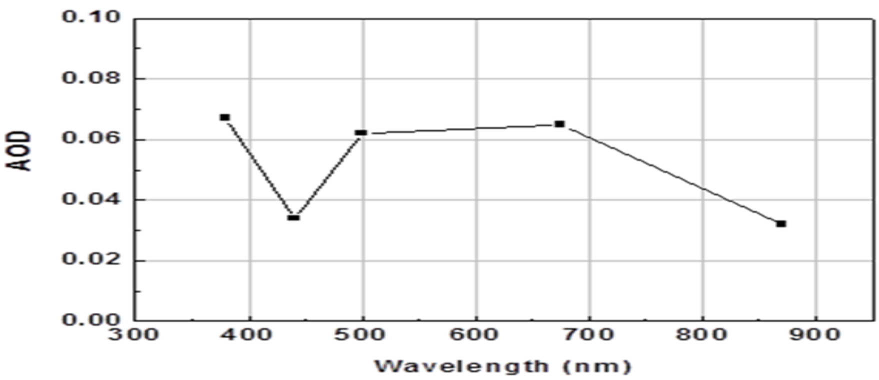

Figure 14: Plot of AOD vs wavelengths.

Expected Outcomes

The oceanographic and atmospheric data acquired during SOE-10 from 27°S to 67°S coving different fronts of Southern Ocean (SO) and Antarctica coast, provides,

1. Broad understanding of the bio-optical variability i.e., variability of apparent and inherent optical properties and understand the potential phytoplankton functional types existing in the ocean and can be further investigated to understand its role in ecosystem functioning.
2. Broad understanding of photosynthetic efficiency (F_v/F_m), absorption cross section of Photosystem (σ_{PSII}) of phytoplankton and estimation of GPP (Gross Primary Productivity) in Southern Ocean and Fluorescence Light Curves (FLCs) for polar fronts.
3. Understanding the role of SO in global carbon cycle and radiative budget using the measurements of Green House Gas concentrations and aerosol.
4. Understanding the rainfall characteristics in the Southern Ocean and Antarctica coast.

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5.4 Biogeochemistry along coastal Antarctica (Prydz bay) and different frontal system of Indian Sector of Southern Ocean

Introduction:

Fossil-fuel combustion releases carbon dioxide (CO_2) to the atmosphere, leading to a warmer climate. But there is another direct impact of increasing CO_2 in the atmosphere. It is changing the chemistry of the ocean. The Southern Ocean provides a critical link in the large-scale ocean circulation and makes significant contributions to global budgets of heat, carbon, freshwater and nutrients. Southern Ocean covers a fifth of the global ocean surface area, yet accounts for approximately 40% of the global anthropogenic carbon dioxide (CO_2) uptake (Sabine et al., 2004). When CO_2 dissolves in seawater, it forms carbonic acid. As this ocean acidification continues, it decreases both ocean pH and the concentration of carbonate ion, the basic building block of the shells and skeletons of many marine organisms. Since the beginning of the Industrial Revolution, ocean acidity (defined here as the hydrogen ion concentration) has increased by 30%. This change is about 100 times faster than any change in acidity experienced during the last many millions of years. Within only a few decades, surface waters in the coldest parts of the ocean are projected to start becoming corrosive to the calcium carbonate shells of some marine organisms. But large unknowns, including the potential for organisms to adapt and the propagation of effects through ecosystems, need to be studied in order to evaluate ecological and economical impacts. The effect of ocean acidification is more pronounced in the cold polar waters, and acidification of the Southern Ocean is likely to impact on several key biogeochemical processes including plankton community structures, and nutrient and alkalinity cycles, formation of calcium carbonate particles, and ballasting of organic carbon in the sinking particulate fluxes. Carbon and nutrient cycling in the Southern Ocean are regulated by a complex interplay of physical, biological and biogeochemical processes, most of which are not well understood. The present study, integrating biogeochemical cycling of Carbon-di-oxide, Dissolved Gases, Macro nutrients and SPOM, was designed and implemented to improve our scientific understanding and predictive capability of the Southern Ocean ecosystem.

Objectives

The principle objectives of the present study are-

- Investigate the cycling and fate of carbon dioxide in the shallowcoastal Antarctica and along different frontal systems.

- To understand the nutrient dynamics – processes governing its distribution.
- Identify the sources and processes that determine the biogeochemical cycling of suspended particulate organic matter.

Materials and methods

Sampling along Coastal Antarctica (Prydz Bay) and different fronts along the Southern Ocean

The samplings for hydrographical and biogeochemical surveys along the water column from surface to bottom were done at 12 stations along Prydz bay, Costal Antarctica. 7 stations (4 at PF2, 1 at PF1, 1 at SAF and 1 at STF) were sampled till 4000m along different fronts in the Indian sector of Southern Ocean. Additional 4 stations were sampled till 2000m near Kerguelen Islands to instigate the island mass effect on biogeochemistry. The details of sampling locations are listed in Figure 15 and Table:11.

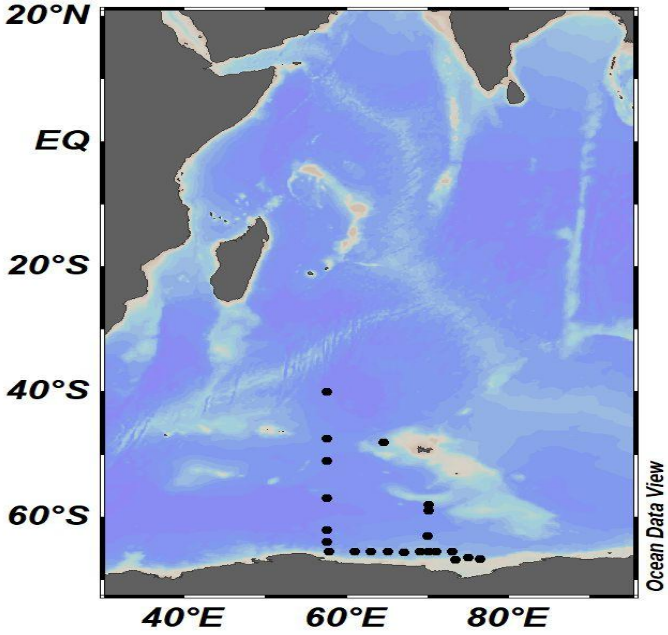

Figure 15: Multidisciplinary sampling locations for biogeochemical studies during SOE-10

Table 11. Particulars of sampling locations along Prydz bay, different fronts of Southern Ocean and near Kerguelen Islands

Date	Stations	Latitude	Longitude	Sampling depth (m)	Parameters collected
15-12-17	Stn #1	-39.996	57.5008	0,10,30,50,75,100,120, 150,200, 500,750 ,1000, 2000, 3000 and 4000m	Oxygen, Carbon dioxide system (DIC, Alkalinity and pH) Nutrients, TOC, dissolved $^{15}NO_3$ isotope, POC, PON, stable isotopic ratio of C & N in POM, Amino acids, & monosaccaride in POM.
20-12-17	Stn #2	-47.9978	64.4651		
23-12-17	Stn #3*	-54.0384	68.1702		
25-12-17	Stn #4	-58.0145	70.0566		
26-12-17	Stn #5**	-58.9995	69.9997		
27-12-17	Stn #6	-63.0146	69.987		
30-12-17	Stn #7	-65.5017	70.008		
31-12-17	Stn #9	-65.5024	72.9956		
01-01-18	Stn #11	-66.8228	73.3829		
02-01-18	Stn #13	-66.4826	74.9033		
03-01-18	Stn #TS	-66.6469	76.3801		
08-01-18	Stn #17	-65.5005	70.9925		
09-01-18	Stn #19	-65.5013	68.9958		
10-01-18	Stn #21	-65.5971	67.0044		
11-01-18	Stn #23	-65.4973	64.9938		
12-01-18	Stn #25	-65.4983	63.002		
13-01-18	Stn #27	-65.5008	61.0035		
15-01-18	Stn #30	-65.5308	57.8517		
16-01-18	Stn #31	-64.0019	57.50202		
17-01-18	Stn #32	-62.0021	57.4996		
21-01-18	Stn #33	-56.9873	57.5075		
24-01-18	Stn #34	-51	57.5		
25-01-18	Stn #35	-47.4948	57.5004		
29-01-18	Stn #36	-39.9875	57.50451		

**Only nutrients CTD operation terminated after one cast due to rough weather*
***Only oxygen, since it's a sole SOCCOM station other parameters were collected by SIO*

Time series observation at Coastal Antarctica

To understand the diurnal variations in carbon dioxide system and associated nutrient and oxygen dyanamics, a 72 hrs time series observations were carried out at Prydz bay, coastal Antarctica. The station location was at 66.65^{o}S and 76.38^{o}E. Samples were collected every 12 hours. The details of sampling are listed in Table 12.

Table 12. Particulars of time series sampling

Date	Stations	Latitude	Longitude	Sampling depth (m)	Parameters collected
03-01-18	T#1	-66.6469	76.3801	0,10,30,50,75,100,120, 150, and 200	Nutrients, Oxygen, Carbon dioxide system (DIC, Alkalinity and pH) POC,PON, ^{13}C-^{15}N isotopes in Particulate organic matter and amino acids and monosaccaride in POM
04-01-18	T#2				
04-01-18	T#3				
05-01-18	T#4				
05-01-18	T#5				
06-01-17	T#6				

Physico-chemical profiling

Profiles of temperature and salinity were obtained from by CTD system (Sea-Bird Electronics). Water samples were collected from 12-15 preselected standard depths (0, 10, 30, 50, 75, 100, 120,150, 200, 300, 500, 750, 1000, 1500, 2000, 3000 and 4000 m) with free-flow Niskin bottles (10l) attached to CTD-rosette system. To study the carbon-di-oxide system pH and total alkalinity were measured on board. pH was data obtained using a Metrohm pH meter and also a Metrohm potentiometer. Total alkalinity was measured using a Metrohm potentiometer. DIC samples were fixed with mercuric chloride and were preserved which will be analysed using UIC coulometer. Dissolved oxygen in water samples were fixed immediately and measured by the Winkler titration method (Grasshoff 1983; detection limit ~2μM). Samples for macro nutrients were poisoned with saturated mercury chloride to stop any biological activities and preserved. The analysis of macro nutrients NO_3^-, NO_2^- , NH_4^+ , PO_4^{3-} and SiO_4^{4-} will be done at laboratory using a SEAL autoanalyser. To study the biogeochemistry of particulate organic matter (POM), samples were collected for particulate organic carbon and nitrogen (POC/PON) and their stable isotopic ratio ($\delta^{13}C$ and $\delta^{15}N$) along with POM samples for amino acid and monosaccaride studies. Samples were collected from 9 standard depths from surface down to 200 m. 5 L of the seawater was filtered immediately through pre-combusted GF/F filters (47 mm diameter, 0.7 μm pore size) under vacuum (~100 mm Hg). The filters were preserved frozen (-20°C) for analysis in NCAOR using an elemental analyzer coupled to an isotope ratio mass spectrometer and HPLC.

Preliminary results

Dissolved Oxygen, Carbon-di-oxide system (pH, DIC and Alkalinity)

In the Prydz Bay, coastal Antarctica, dissolved oxygen concentrationswere found to very high. Surface concentrations were >7ml/l which had reduce to ~ 5ml/l below the mixed layer (Figure 16a). This variations is largely attributed to the ambient temperature. pH is the crucial parameter to study the dissolve CO_2 dynamics and estimate its fluxes along surface ocean and lower atmospheric boundary. Sea water pH is largely depended on temperature which is an important regulator of diffusibility of atmospheric gases into sea water. In the coastal Antarctica along 65.5^{o}S transect we found lower pH gradient compared to tropical and subtropical water (Figure 16b). Diffusibility of CO_2 in this coldest region is large compared to tropic or subtropics, which reduces the pH of the ambient water column.

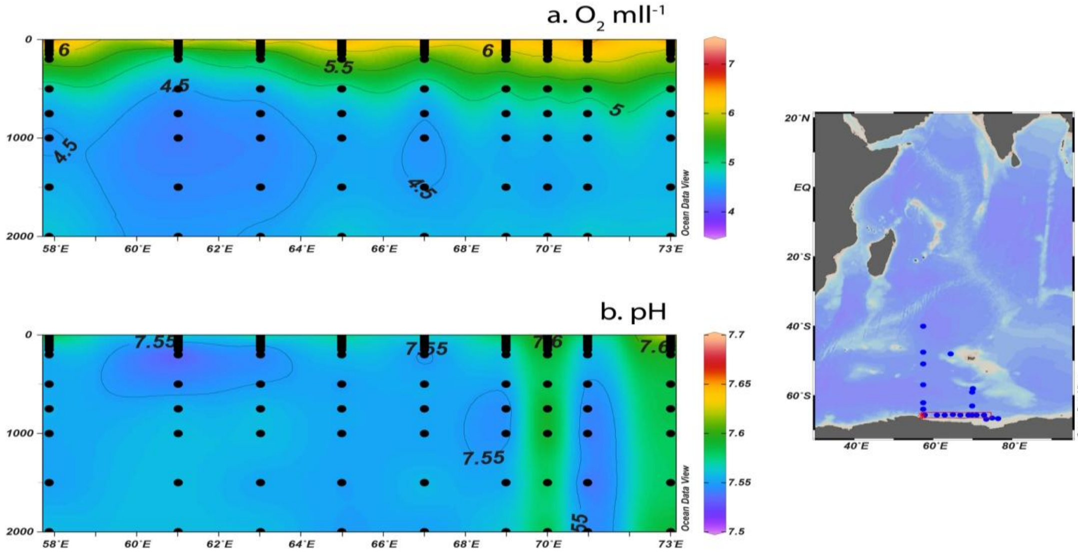

Figure 16 : Oxygen and pH distribution along coastal Antarctica Transect (along 65.5°S latitude)

Surface dissolved oxygen concentration at the sub tropical fronts STF was found to be ~5ml/l (Figure 17a). As temperature decreased towards Polar Regions the surface oxygen concentrations were also elevated. Surface mixed layer also showed similar properties, however, concentrations below 400m depth remained constant.As the temperature varies from one front to another in the southern ocean pH also shows prominent frontal variability. PF being coolest among other fronts of present study could accommodate large volume dissolved CO_2 . Therefore, PF showed lowest sea water pH which has increased gradually while moving towards STF (Figure 17b).

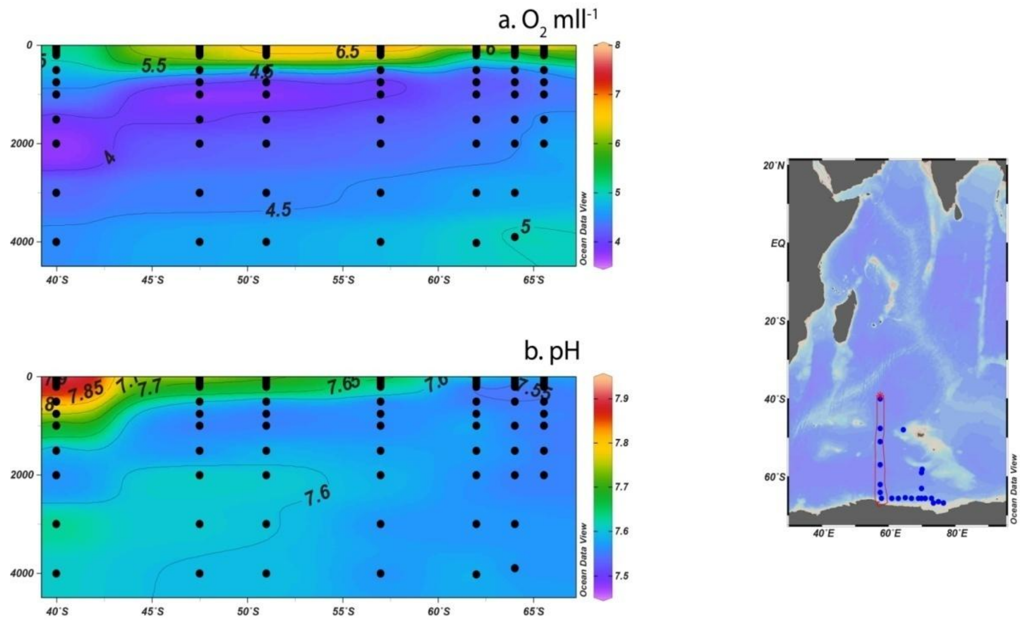

Figure 17: Oxygen and pH distribution along different fronts (along 57.5oE longitude)

Concluding remarks

The data presented in this cruise report are of very crude in nature. The preliminary discussions were also made to just get a brief idea of the distribution of few biogeochemical parameters (Oxygen and pH in this case) along the cruise track. All data are needed further quality check and processing.

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5.5. Phytoplankton taxonomy, physiology and biogeochemical studies

Introduction

Phytoplankton the vital component of the ocean's ecological and biogeochemical system are the key drivers in the cycling of the elements and plays role in the regulation of atmosphere carbon dioxide. The cycling of the carbon in particular is modulated by the phytoplankton through the mechanism of photosynthesis and respiration (Aiken et al 1992). The variation of phytoplankton biomass, production and groups leads ecosystem of varying trophic status, characterizes the oceans and hence need to quantify on basin wide and global scale (Maranon et al. 2000). Knowledge on the qualitative and quantitative distribution of phytoplankton will be of fundamental importance in any attempt to understand the biological response to climate variability. In addition to light microscopic analysis of phytoplankton, the phytoplankton pigments contribute to the portrayal of taxonomy of various algal classes and can be used diagnostically to classify the presence of individual groups in the natural samples. However, trough the analysis of water samples, will get snapshot view of present distribution of the phytoplankton community in the study area and to the long term variation in such community structure is very important. Hence the benthic pelagic coupling approach was used in the present study by collecting the sediment samples from the study area.

Objectives

In view of the above the following objective was undertaken to study

1) To study the phytoplankton community structure by using different techniques (Light microscopy, High Performance Liquid Chromatography (HPLC), Fluorometer and Flowcytometery).

2) Study of phytoplankton physiology and their role in Biogeochemical cycle

3) Collection of sediment core to study the temporal distribution of diatoms and dinoflagellate cyst.

Material and Methods

To accomplish the above objective, the water samples were collected from total 22 stations including one three-day time series along the study transect of the Indian sector of Southern Ocean (Table. 14).The sampling depths (0, 10, 30, DCM, 100, 120m) were selected after taking light and deep chlorophyll maxima into consideration. The water samples were used for sample fixing for light microscopy, Flowcytometery and water filtration for chlorophyll/pigment analysis as follows:

Table 14. Particulars of water sampling locations and collections

Sl. No	Station No.	Date	Latitude	Longitude	Sample Depth(m)	Parameters Collected
1	1	15-12-2017	39.59	57.3	0, 10,30 DCM, 100 and 120	Chlorophyll, HPLC pigments, Phytoplankton taxonomy and Pico-phytoplankton Studies
2	2	20-12-2017	47.59	64.27	0, 10,30 DCM, 100 and 120	
3	4	25-12-2017	58	69.59	0, 10,30 DCM, 100 and 120	
4	6	28-12-2017	63	69.59	0, 10,30 DCM, 100 and 120	
5	7	30-12-2017	65.3	75	0, 10,30 DCM, 100 and 120	
6	9	31-12-2017	65.3	72.59	0, 10,30 DCM, 100 and 120	
7	11	01-01-2018	66.49	73.22	0, 10,30 DCM, 100 and 120	
8	13	02-01-2018	66.28	74.54	0, 10,30 DCM, 100 and 120	
9	15TS	03-01-2018	66.38	76.22	0, 10,30 DCM, 100 and 120	
10	17	08-01-2018	65.3	70.59	0, 10,30 DCM, 100 and 120	
11	19	09-01-2018	65.3	68.59	0, 10,30 DCM, 100 and 120	
12	21	10-01-2018	65.29	67	0, 10,30 DCM, 100 and 120	
13	23	11-01-2018	65.29	64.59	0, 10,30 DCM, 100 and 120	
14	25	12-01-2018	65.29	63	0, 10,30 DCM, 100 and 120	
15	27	13-01-2018	65.3	61	0, 10,30 DCM, 100 and 120	
16	30	15-01-2018	65.31	57.51	0, 10,30 DCM, 100 and 120	

17	31	16-01-2018	64	57.3	0, 10,30 DCM, 100 and 120	
18	32	17-01-2018	62	57.29	0, 10,30 DCM, 100 and 120	
19	33	21-01-2018	56.59	57.3	0, 10,30 DCM, 100 and 120	
20	34	24-01-2018	51	57.37	0, 10,30 DCM, 100 and 120	
21	35	25-01-2018	47.29	57.3	0, 10,30 DCM, 100 and 120	
22	36	29-01-2018	39.59	57.3	0, 10,30 DCM, 100 and 120	
Sediment Core Sampling						
Sl. No.	**Station details**	**Date**	**Latitude**	**Longitude**		
1	Core 1-15c.m		66.49	73.15		
2	Core 2-3.7m	7/1/2018	66.27	73.18		
3	Core 3-3.7m	14/1/2018	65.32	56.5		

Sample collection for Light Microscopy

500mL of water samples from each depth were fixed with Lugol's solution and the samples were kept in dark and cool place for its further onshore laboratory analysis. In addition to this, few samples across each front were taken for piccoplankton analysis through flowcytometery. Samples were flash frozen using liquid nitrogen.

Sample collection for pigment analysis

Knowledge of the range of photosynthetic pigments in a sample can indicate the algal classes present in phytoplankton communities, information not available from simple chlorophyll and 'pheopigment' analyses. The application of HPLC in phytoplankton studies has extended the range of pigment separations. The chromatographic methods separate an array of chlorophylls and carotenoids, which act as indicators of phytoplankton biomass, and biological markers for algal types.

In light of the above, 3-4L samples from each depth and station were filtered through GF/F filters (0.7 µm) and the filters were stored in -20^{0}C temperature to avoid the degradation of the pigment. The filtration was carried out at low temperature and dim light condition. The analysis of the samples will be carried out at onshore laboratories. Due to sensitivities of HPLC instruments and non-availability of this on board, the phytoplankton pigment analysis could not analyse on board and hence stored in cold freezer and brought to onshore laboratory for further analysis.

Expected Outcome

The previous result has been showed the greater variability and dominance of phytoplankton communities from subtropical front (STF) to polar front (PF) of the Indian sector of Southern Ocean. The Diatom increased its population from STF to PF, whereas the Flagellate decreased from STF to PF and Pico phytoplankton again increased from STF to PF, the similar trend expected from this year result to understand the physiology of phytoplankton and response of physical forcing to the variability of communities and their role in biogeochemical cycles.

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5.6 Phytoplankton productivity and bio-optical studies

Introduction

Ocean contains thousands of free-floating, microscopic plants called "phytoplankton". Arguably one of the most consequential activities of marine phytoplankton is their influence on global carbon cycle and climate (Falkowski, 2002). All phytoplankton photosystem contains a pigments named chlorophyll-a, which traps the incident sunlight, fix the CO_2, release O_2 (primary productivity) and produce organic matter which serves as source of food for virtually all other marine life forms. Thus, they play a vital role in sustenance of almost all life forms in the marine ecosystem. The sequestration of atmospheric CO_2 fluxes to the deep ocean by primary production (i.e., biological Pump) varies as a function of light regime, temperature, nutritional status and other environmental forcing. Through biological pump an estimate of 11 to 16 Pg of atmospheric CO_2 from surface waters of the world's oceans is being removed per year; which accounts for 12-18% of the total carbon sequestration by the ocean (Falkowski et al., 2000). The Southern Ocean (SO) acts as a sink for atmospheric CO_2 via the solubility and biological pumps (Chisholm et al., 2001; Tripathy et al., 2017) and, thus plays a pivotal role in the global carbon cycle and climatic regulations. In the Indian sector, it has been reported that magnitude of phytoplankton productivity (PP) can be influenced by pigment packaging and presence of deep chlorophyll maximum (Tripathy et al., 2014, 2015), as well as strongly influenced by nutrient-laden freshwater inlux from melting sea ice (Sabu et al., 2014). A major goal in understanding how ocean dynamics and bio-optics affect phytoplankton biomass, production and carbon cycles is to determine how photosynthetic processes respond to geochemical and physical phenomena. Understanding these relationships is critical for studying the global carbon cycle and climate change pattern (JGOFS, 2002). However, knowledge on this aspect is scanty in the Indian sector of SO. Therefore, attempts were made to explore more on these aspects.

Objectives

1. To study the environmental forcing controlling PP in the study area. Compare ^{14}C, ^{13}C and FRRF-based PP estimates to know their relationship.
2. Bi-optical characterization of waters using apparent optical properties (AOP) and inherent optical properties (IOP) measurements in the Indian sector of SO.

3. Surface mapping of phytoplankton physiological parameters by FRRF measurements. (F_V/F_M, σ_{PSII}) along the cruise track, which can be used as an indicator of nutrient and light limitation in the study area.

Materials and Methods

Water samples were collected for measurements of phytoplankton absorption (a_{ph}), absorption by coloured dissolved organic matter (a_{CDOM}), phytoplankton biomass (Chl-a), total suspended matter (TSM) and primary productivity by simulated *in situ* methods using ^{13}C (stable isotope) and ^{14}C (radio-active isotope) following standard procedures (JGOFS, 2002). Optical instruments like hyperspectral radiometer (HyperPro II, Satlantic, Canada) and fast repetition rate fluorometer (FRRF, CTG, UK) were profiled up to 200 m at multidisciplinary stations. Details of the water sampling at surface layer (Table 15), vertical water column (Table 16) and time series station (Table 17) can be found in subsequently. The Figure 18 depicts study area map with sampling locations. Incident photosynthetically active radiation (PAR) was measured continuously on board using a QSL-2100 PAR sensor fitted at a shadow free area on monkey deck. Due to malfunctioning of associated laptop the PAR data could not be collected in the initial days of the expedition and data is available only from 03/01/2018. Observations by inherent optical profiler (IOP, WETLABs) at multidisciplinary stations, FRRF-based continuous measurements (dark chamber only) of surface water, fluorescence-light curve (FLC) measurements by FastAct were carried out in a collaborative effort with National Remote Sensing Centre (NRSC-ISRO) scientists. Some of the scientific activities performed onboard were outlined in Figure 19.

Table 15. Overview of the surface water sampling stations

Sl. No.	Station ID	Latitude (°S)	Longitude (°E)	Sampling		Parameters Measured			
				Date	Local Time (Hrs)	a_{ph}	Chl-a	TSM	CDOM
1	SS-1	26° 18.79	57° 45.99	11/12/2017	11:50	✓	✓	✓	✓
2	SS-2	27° 41.70	57° 50.44	11/12/2017	19:30	✓	✓	✓	✓
3	SS-3	30° 40.36	58° 00.40	12/12/2017	11:50	✓	✓	✓	✓
4	SS-4	31° 41.39	58° 03.15	12/12/2017	17:55	✓	✓	✓	✓
5	SS-5	34° 48.52	58° 12.48	13/12/2017	11:29	✓	✓	✓	✓
6	SS-6	35° 55.44	58° 15.53	13/12/2017	17:45	✓	✓	✓	✓
7	SS-7	39° 13.85	58° 27.24	14/12/2017	11:25	✓	✓	✓	✓

8	SS-8	40° 12.20	58° 31.39	14/12/2017	17:20	✓	✓	✓	✓
9	SS-9	40° 11.95	58° 24.57	17/12/2017	11:30	✓	✓	✓	✓
10	SS-10	40° 16.74	58° 31.11	17/12/2017	17:40	✓	✓	✓	✓
11	SS-11	42° 31.26	60° 15.52	18/12/2017	11:30	✓	✓	✓	✓
12	SS-12	43° 09.39	60° 40.33	18/12/2017	17:35	✓	✓	✓	✓
13	SS-13	45° 09.45	62° 14.92	19/12/2017	11:35	✓	✓	✓	✓
14	SS-14	46° 08.18	62° 59.13	19/12/2017	17:45	✓	✓	✓	✓
15	SS-15	50° 28.36	64° 26.43	21/12/2017	11:35	✓	✓	✓	✓
16	SS-16	50° 59.83	63° 23.35	21/12/2017	17:45	✓	✓	✓	✓
17	SS-17	53° 00.29	65° 22.71	22/12/2017	11:40	✓	✓	✓	✓
18	SS-18	53° 32.57	66° 46.01	22/12/2017	17:45	✓	✓	✓	✓
19	SS-19	54° 00.52	68° 11.61	23/12/2017	13:15	✓	✓	✓	✓
20	SS-20	54° 04.48	68° 06.96	23/12/2017	17:45	✓	✓	✓	✓
21	SS-21	55° 58.05	69° 26.55	24/12/2017	11:25	✓	✓	✓	✓
22	SS-22	56° 30.68	69° 00.00	24/12/2017	17:50	✓	✓	✓	✓
23	SS-23	59° 32.86	70° 55.75	26/12/2017	11:40	✓	✓	✓	✓
24	SS-24	60° 08.02	71° 34.93	26/12/2017	17:25	✓	✓	✓	✓
25	SS-25	62° 30.88	70° 07.85	27/12/2017	11:40	✓	✓	✓	✓
26	SS-26	64° 18.49	70° 45.75	28/12/2017	11:50	✓	✓	✓	✓
27	SS-27	65° 10.44	71° 45.80	28/12/2017	17:40	✓	✓	✓	✓
28	SS-28	66° 29.12	74° 40.53	29/12/2017	12:50	✓	✓	✓	✓
29	SS-29	66° 59.25	75° 16.94	07/01/2018	11:15	✓	✓	✓	✓
30	SS-30	58° 55.47	54° 49.61	20/01/2018	11:50	✓	✓	✓	✓
31	SS-31	58° 40.43	55° 08.24	20/01/2018	18:08	✓	✓	✓	✓
32	SS-32	54° 28.92	57° 20.39	22/01/2018	17:10	✓	✓	✓	✓
33	SS-33	52° 22.19	57° 00.60	23/01/2018	11:50	✓	✓	✓	✓
34	SS-34	51° 49.44	56° 14.02	23/01/2018	17:45	✓	✓	✓	✓
35	SS-35	45° 54.10	57° 43.87	26/01/2018	12:00	✓	✓	✓	✓
36	SS-36	44° 53.99	57° 53.46	26/01/2018	18:00	✓	✓	✓	✓
37	SS-37	42° 01.01	58° 15.38	27/01/2018	11:35	✓	✓	✓	✓
38	SS-38	41° 01.32	58° 23.26	27/01/2018	17:33	✓	✓	✓	✓
39	SS-39	40° 11.10	58° 24.23	28/01/2018	12:00	✓	✓	✓	✓
40	SS-40	40° 10.75	58° 31.57	28/01/2018	17:31	✓	✓	✓	✓

***a_{ph}: Light absorption by phytoplankton, **Chl-a**: Chlorophyll-a, **TSM**: Total suspended matter, **CDOM**: Coloured dissolved organic matter*

Table 16. Overview of the water column sampling and profiling of different instruments

Sl. No	Stn. ID	Lat. (^{o}S)/ Long.(^{o}E)	Sampling			Parameters Measured/ Instruments Operated							
			Date	Time (Hrs)	Depth (m)	Bio-optical				PP		Instruments	
						a_{ph}	Chl-a	TSM	CDOM	^{13}C	^{14}C	Hyper Pro II	FRRF
1	Stn-1	39^{o} 59.76/ 57^{o} 30.05	15/12/17	15:33	*Six sampling depths were chosen based on the light penetration (%) in the water column. [Sampling depths ranges from 0-120 m; Instruments were lowered up to 200 m]*	✓	✓	✓	✓				✓
2	Stn-2	47^{o} 59.87/ 64^{o} 27.91	20/12/17	09:55		✓	✓	✓	✓	✓			✓
3	Stn-4	58^{o} 00.00/ 69^{o} 59.65	25/12/17	07:55		✓	✓	✓	✓	✓			✓
4	Stn-6	63^{o} 00.88/ 69^{o} 59.24	27/12/17	23:35		✓	✓	✓	✓	✓		✓	✓
5	Stn-7	65^{o} 30.10/ 70^{o} 00.52	30/12/17	07:10		✓	✓	✓	✓	✓	✓	✓	✓
6	Stn-9	65^{o} 30.14/ 72^{o} 59.73	31/12/17	06:58		✓	✓	✓	✓			✓	✓
7	Stn-11	66^{o} 49.37/ 73^{o} 22.97	01/01/18	13:47		✓	✓	✓	✓	✓	✓	✓	✓
8	Stn-13	66^{o} 28.95/ 74^{o} 54.20	02/01/18	18:47		✓	✓	✓	✓	✓		✓	✓
9	Stn-17	65^{o} 30.03/ 70^{o} 59.55	08/01/18	10:16		✓	✓	✓	✓	✓		✓	✓
10	Stn-19	65^{o} 30.08/ 68^{o} 59.75	09/01/18	09:00		✓	✓	✓	✓	✓		✓	✓
11	Stn-21	65^{o} 29.82/ 67^{o} 00.26	10/01/18	08:27		✓	✓	✓	✓	✓		✓	✓
12	Stn-23	65^{o} 29.84/ 64^{o} 59.63	11/01/18	08:40		✓	✓	✓	✓	✓	✓	✓	✓
13	Stn-25	65^{o} 29.90/ 63^{o} 00.15	12/01/18	09:23		✓	✓	✓	✓	✓		✓	✓
14	Stn-27	65^{o} 30.05/ 61^{o} 00.21	13/01/18	08:36		✓	✓	✓	✓	✓	✓	✓	✓
15	Stn-30	65^{o} 31.85/ 57^{o} 51.10	15/01/18	11:37		✓	✓	✓	✓	✓		✓	✓
16	Stn-31	64^{o} 00.12/ 57^{o} 30.12	16/01/18	10:15		✓	✓	✓	✓	✓			✓
17	Stn-32	62^{o} 00.13/ 57^{o} 29.98	17/01/18	14:09		✓	✓	✓	✓	#		✓	✓
18	Stn-33	56^{o} 59.24/ 57^{o} 30.45	21/01/18	15:01		✓	✓	✓	✓	#	#	✓	✓
19	Stn-34	51^{o} 00.19/ 57^{o} 30.60	24/01/18	08:22		✓	✓	✓	✓	✓	✓	✓	✓
20	Stn-35	47^{o} 29.69/ 57^{o} 30.02	25/01/18	18:15		✓	✓	✓	✓	✓	✓	✓	✓
21	Stn-36	39^{o} 59.61/ 57^{o} 30.21	29/01/19	23:00		✓	✓	✓	✓	✓	✓	✓	✓

***a_{ph}: Light absorption by phytoplankton, **Chl-a**: Chlorophyll-a, **TSM**: Total suspended matter, **CDOM**: Coloured dissolved organic matter, **PP**: Primary productivity, **HyperProII**: Hyperspectral radiometer (measures E_u, E_d, R_{rs}), **FRRF**: Fast repetition rate fluorometer (measures F_v/F_m, σ_{PSII}, ETR), #: Samples lost due to bad weather.*

Table 17. Sampling overview of the time series [@12h interval for 3 days] station

Sl. No	Stn. ID	Lat. (°S)/ Long. (°E)	Sampling			Parameters Measured/ Instruments Operated							
			Date	Time (Hrs)	Depth (m)	Bio-optical				PP		Instruments	
						a_{ph}	Chl-a	TSM	CDOM	^{13}C	^{14}C	Hyper Pro II	FRRF
1	TS-1	66°38.81/ 76°22.81	03/01/18	08:37	*Six sampling depths: 0-120 m Instruments: lowered up to 150 m*	✓	✓	✓	✓			✓	✓
2	TS-2	66°34.65/ 76°24.38	03/01/18	18:52		✓	✓	✓	✓	✓		✓	✓
3	TS-3	66°33.80/ 76°25.22	04/01/18	06:44		✓	✓	✓	✓			✓	✓
4	TS-4	66°33.24/ 76°22.05	04/01/18	18:52		✓	✓	✓	✓	✓		✓	✓
5	TS-5	66°34.12/ 76°18.95	05/01/18	06:58		✓	✓	✓	✓			✓	✓
6	TS-6	66°39.01/ 76°19.65	05/01/18	19:58		✓	✓	✓	✓	✓	✓	✓	✓
7	TS-7	66°38.98/ 76°16.50	06/01/18	07:50		✓	✓	✓	✓			✓	✓

*** Legends same as mentioned in Table 2.*

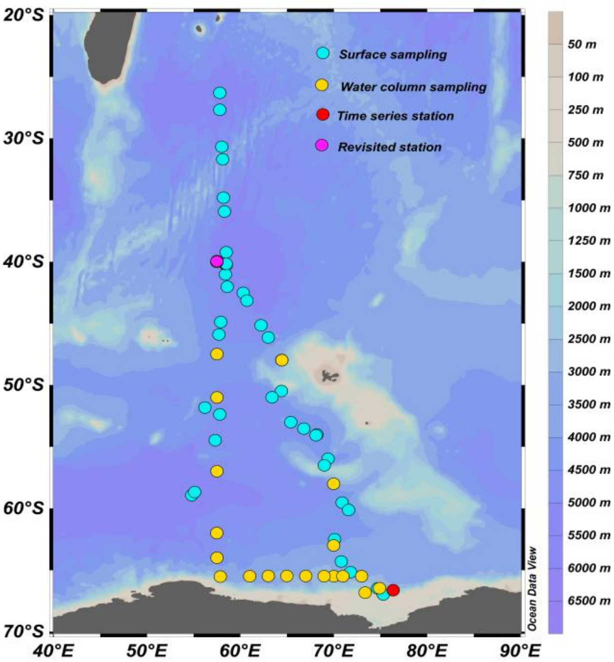

Figure 18: Sampling locations for primary productivity and/or bio-optical mesurements. The blue, yellow, red and pink dots indicate surface sampling, water column sampling, time series station and the station revisited after 45 days, respectively.

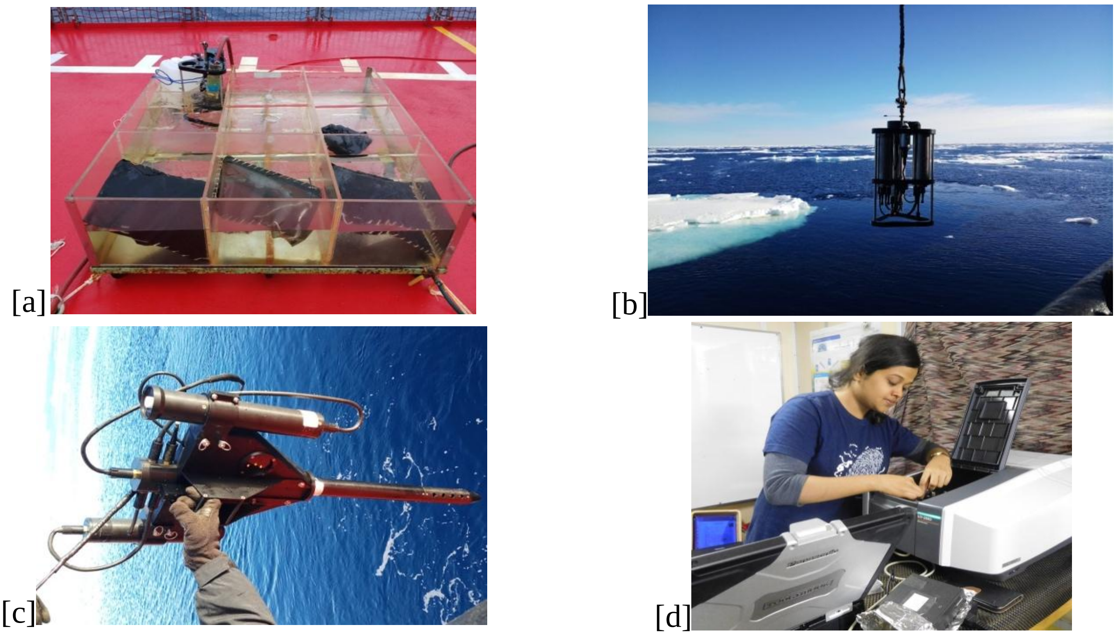

Figure 19: Scientific activities showing (a) on deck SIS incubation for C-uptake experiment, deployment of (b) FRRF and (c) HyperPro II, (d) spectrophotometric measurements

Preliminary results

Screenshots of measurements done by optical instruments are given hereunder. Detailed analysis shall be carried out at the shore laboratory.

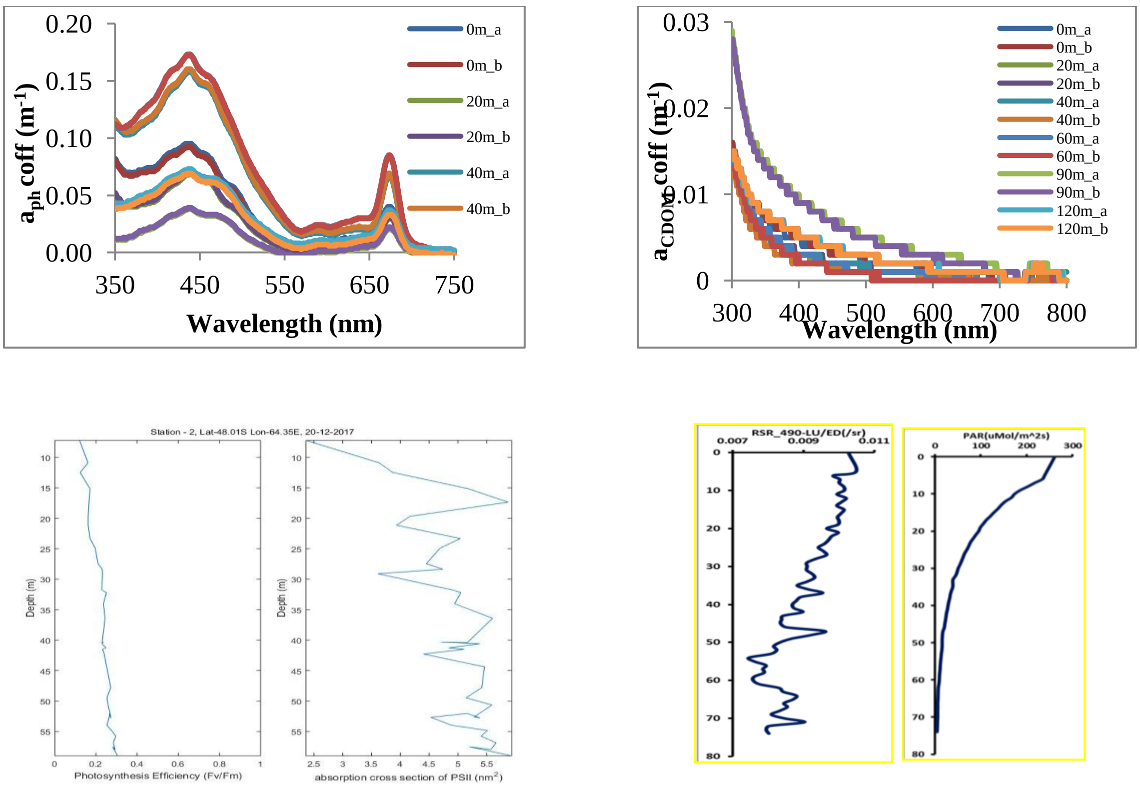

Figure 20: Absorption coefficient of phytoplankton (top L), CDOM (top R) in the water column. Vertical profiles of F_v/F_m and σ_{PSII} (bottom L), remote sensing reflectance and PAR (bottom R).

Expected Outcome

Information on PP is scanty in the Indian sector of the SO. Therefore, these on-deck experiments would provide useful information of C-uptake for the study area, which shall help us in understanding the physicochemical forcings responsible for controlling the carbon sequestration/biological pump efficiency in SO. FRRF measurements are expected to through light on the nutrient limitation on the physiological status of phytoplankton. Measurements of bio-optical parameters (a_{ph}, a_{CDOM}, Chl-a, TSM), AOP and IOP shall be used for understanding the light-absorption efficiency by phytoplankton and generate baseline data for under water light fields respectively. Light is considered as the most dominant factor for photosynthesis; together with TSM information we can study the role of underwater light attenuation in controlling PP. Optical measurements will be very useful in ocean color remote sensing applications.

References

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5.7 Zooplankton diversity, migration and biogeochemical studies

Introduction

Mesozooplankton are a group of multicellular organisms (size range: 200 µm to 2 mm) that feed on phytoplankton, microzooplankton, other mesozooplankton and detritus. They are the important link between primary producers and higher tropic levels in sub-polar and polar waters as well as in tropical waters. Thus, they are the largest organisms play a pivotal role in global biogeochemical of the marine carbon cycle.

The Southern Ocean (SO) is not ecologically uniform and is subdivided into several distinct circumpolar zones by strong frontal systems. The frontal systems are represent important boundaries to the distribution of planktonic species due to their strong physico-chemicial gradients. The frontal systems themselves are characterised by increased biological productivity and biomass at all trophic levels of the pelagic ecosystem (Pakhomov et al. 1994). Differences in zooplankton communities are expected in each of the fronts. As in other oceans, copepods dominate the total mesozooplankton across most of the SO in terms of biomass, abundance and grazing activity.

Zooplankton vertical distribution profiles have been examined in different regions of the Indian sector of SO to study the impact of environmental factors on the patterns in zooplankton profiles. Up to now the study of zooplankton community in the Indian sector of the Southern Ocean and coastal Antarctica has been limited. Vertical profiles of the zooplankton community structure in the mesopelagic and bathypelagic zones of Indian sector of Southern Ocean also have been less reported. It is unclear whether the latitudinal distribution patterns of epipelagic zooplankton communities also exist in the mesopelagic and bathypelagic zones.

In this present scenario the objectives of the study were to investigate the physical and biological mechanism(s) that mediate the abundance and distribution patterns of zooplankton communities, in respect to horizontal and vertical migration in the Indian sector of the SO .

Objectives

- To examine the inter-annual variability of mesozooplankton biomass and community structure in the Indian sector of the Southern Ocean and coastal Antarctica.
- To understand the influencing and controlling factors for zooplankton diel vertical migration in the coastal Antarctica.

Materials and Methods

Sampling took place during the 10th Southern Ocean expedition during studies on biogeochemistry and hydrodynamics on board *S.A. Agulhas*.The data were collected between the 15th December 2017 and 30th of January 2018 from 40° South to 66° South, covering different frontal regions of Southern Ocean and coastal Antarctica. (Table. 1 and Table. 2). Subsequently the time series observations were carried out at fixed location (66°.36.84S 76°.24.75E) from 3rd to 6th January 2018. For every 12hrs intervals the mesozooplankton samples were collected from desirable depths (1000m), and from sea surface (<1m) (Table. 3).

A Multiple Plankton Sampler (MPS) consist of 0.25 m^2 mouth and 200 µm mesh (Fig. 1) was used at each station to collect the vertical mesozooplankton samples from different depths up to 1000m. Five standard depths were sampled (table 1). The mesozooplankton samples were also collected from the ocean surface by horizontal towing of Bongo net (200-µm mesh size) (Fig.2) for 10-15 minutes at a speed of ~2.5 to 3 knots. The volume of water filtered by the net was measured with a calibrated mechanical flow meter (Hydro-Bios;Fig.2) mounted at the mouth of the net (0.32 m^2). Collected mesozooplankton (Fig.3&4)sampleswere preserved immediately with 5% neutralized formalin/seawater after capture. Preserved samples were brought to the NCAOR laboratory for further analysis i.e. qualitative and quantitative analysis.

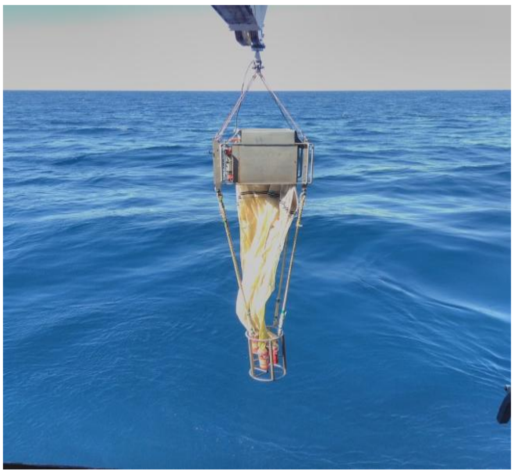

Figure 21: Vertical hauling of Multi Plankton Sampler for zooplankton collection.

Figure 22: Horizontal towing of bongo net for surface zooplankton collection

Expected outcome

From the present study, it is expected that the influence of the (1) physical (temperature and salinity) and biological (total chlorophyll-a) processes on zooplankton cause the effect of diel vertical migration and distribution of community structure in the frontal regions of Indian sector of SO and coastal Antarctica. This would help for further an understanding of the community structure and their role in the biogeochemical cycle in the Indian sector of the Southern Ocean

Table 18. Vertical sampling details for zooplankton biomass and species composition.

Sl. No	Station ID	Latitude Longitude	Date	Time of sampling	Sampling depths	Instrument operated/ Parameters collected
1	#1	40^{o}.04.76 S 57^{o}.30.58 E	15-12-17	13:36	---	Cancelled, due to rough weather
2	#2	48^{o}.00.07 S 64^{o}. 22.73 E	20-12-17	11:15	Surface-1000m	Multi Plankton Sampler
3	#3	54^{o}.01.35 S 68^{o}.06.81 E	23-12-17	12:05	----	Cancelled, due to non-functioning of the winch
4	#4	58^{o}.02.41 S 70^{o}.26.81 E	25-12-17	11:32	Surface-1000m	Multi Plankton Sampler
5	#5	63^{0}.00.51 S 70^{0}.02.34 E	28-12-17	01:40	Surface-1000m	Multi Plankton Sampler
6	#6	65^{0}.31.82 S 74^{0}.58.11 E	30-12-17	08:50	Surface-1000m	Multi Plankton Sampler
7	#7	65^{0}.29.92 S 73^{0}.00.84 E	31-12-17	12:57	Surface-1000m	Multi Plankton Sampler
8	#8	66^{0}.48.74 S 73^{0}.16.73 E	01-01-18	15:57	Surface-1000m	Multi Plankton Sampler
9	#9	66^{0}.25.40 S 75^{0}.01.20 E	02-01-18	13:45	Surface-1000m	Multi Plankton Sampler
10	#10	65^{0}.29.96 S 70^{0}.58.66 E	08-01-18	11:50	Surface-1000m	Multi Plankton Sampler
11	#11	65^{0}.30.18 S 69^{0}.00.33 E	09-01-18	10:05	Surface-1000m	Multi Plankton Sampler
12	#12	65^{0}.30.18 S 67^{0}.00.37 E	10-01-18	09:20	Surface-1000m	Multi Plankton Sampler
13	#13	65^{0}.30.33 S 64^{0}.59.34 E	11-01-18	10:10	Surface-1000m	Multi Plankton Sampler
14	#14	65^{0}.29.90 S 63^{0}.00.15 E	12-01-18	11:10	Surface-1000m	Multi Plankton Sampler
15	#15	65^{0}.30.29 S 61^{0}.00.25 E	13-01-18	09:35	Surface-1000m	Multi Plankton Sampler
16	#16	65^{0}.30.13 S 57^{0}.51.09 E	15-01-18	14:31	Surface-1000m	Multi Plankton Sampler
17	#17	64^{0}.00.05 S 57^{0}.28.38 E	16-01-18	13:39	-----	Cancelled, due to rough weather
18	#18	62^{0}.00.99 S 57^{0}.28.03 E	17-01-18	16:20	Surface-1000m	Multi Plankton Sampler
19	#19	57^{0}.00.27 S 57^{0}.30.45 E	21-01-18	18:15	Surface-1000m	Multi Plankton Sampler
20	#20	51^{0}.00.82 S 57^{0}.29.53 E	24-01-18	12:15	Surface-1000m	Multi Plankton Sampler
21	#21	47^{0}.30.46 S 57^{0}.30.90 E	25-01-18	21:13	Surface-1000m	Multi Plankton Sampler
22	#22	40^{0}.00.30 S 57^{0}.30.12 E	30-01-18	01:40	Surface-1000m	Multi Plankton Sampler

Table 19. Surface sampling details for zooplankton biomass and community structure

Sl. No	Station ID	Latitude Longitude	Date	Time of sampling	Sampling depths	Instrument operated/ Parameters collected
1	#1	40^{o}.04.76 S 57^{o}.30.58 E	15-12-17	20:19	Surface	Bongo net
2	#2	48^{o}.00.07 S 64^{o}. 22.73 E	20-12-17	15:45	Surface	Bongo net
3	#3	54^{o}.01.35 S 68^{o}.06.81 E	23-12-17	14:10	Surface	Bongo net
4	#4	58^{o}.02.41 S 70^{o}.26.81 E	25-12-17	16:20	Surface	Bongo net
5	#5	63^{0}.00.51 S 70^{0}.02.34 E	27-12-17	18:17	Surface	Bongo net
6	#6	65^{0}.31.82 S 74^{0}.58.11 E	30-12-17	13:48	Surface	Bongo net
7	#7	65^{0}.29.92 S 73^{0}.00.84 E	31-12-17	12:57	Surface	Bongo net
8	#8	66^{0}.48.74 S 73^{0}.16.73 E	01-01-18	21:40	Surface	Bongo net
9	#9	66^{0}.25.40 S 75^{0}.01.20 E	02-01-18	13:45	Surface	Bongo net
10	#10	65^{0}.29.96 S 70^{0}.58.66 E	08-01-18	16:45	Surface	Bongo net
11	#11	65^{0}.30.18 S 69^{0}.00.33 E	09-01-18	15:36	Surface	Bongo net
12	#12	65^{0}.30.18 S 67^{0}.00.37 E	10-01-18	13:57	Surface	Bongo net
13	#13	65^{0}.30.33 S 64^{0}.59.34 E	11-01-18	16:55	Surface	Bongo net
14	#14	65^{0}.29.90 S 63^{0}.00.15 E	12-01-18	16:22	Surface	Bongo net
15	#15	65^{0}.30.29 S 61^{0}.00.25 E	13-01-18	17:21	Surface	Bongo net
16	#16	65^{0}.30.13 S 57^{0}.51.09 E	15-01-18	18:51	Surface	Bongo net
17	#17	64^{0}.00.05 S 57^{0}.28.38 E	16-01-18	17:33	Surface	Bongo net
18	#18	62^{0}.00.99 S 57^{0}.28.03 E	17-01-18	20:12	Surface	Bongo net
19	#19	57^{0}.00.27 S 57^{0}.30.45 E	21-01-18	13:20	Surface	Bongo net
20	#20	51^{0}.00.82 S 57^{0}.29.53 E	24-01-18	06:30	Surface	Bongo net
21	#21	47^{0}.30.82 S 57^{0}.30.90 E	25-01-18	11:45	Surface	Bongo net
22	#22	40^{0}.00.30 S 57^{0}.30.12 E	29-01-18	18:20	Surface	Bongo net

Table 20. Time series observations at fixed location.

Sl.No.	Station ID	Latitude Longitude	Date	Time of sampling	Sampling depths	Instrument operated/ Parameters collected
1	#1	66^{o}.36.84 S 76^{o}.24.75 E	03-01-18	09:03	Surface-1000m	MPS/Zooplankton
				12:37	Surface	Bongo net/Zooplankton
				19:00	Surface-1000m	MPS/Zooplankton
				23:05	Surface	Bongo net/Zooplankton
			04-01-18	08:24	Surface-1000m	MPS/Zooplankton
				14:37	Surface	Bongo net/Zooplankton
				19:30	Surface-1000m	MPS/Zooplankton
				23:10	Surface	Bongo net/Zooplankton
			05-01-18	09:45	Surface-1000m	MPS/Zooplankton
				12:50	Surface	Bongo net/Zooplankton
				19:10	Surface-1000m	MPS/Zooplankton
				23:45	Surface	Bongo net/Zooplankton
			06-01-18	11:50	Surface-1000m	MPS/Zooplankton
				15:49	Surface	Bongo net/Zooplankton

Figure 23. Zooplankton sample collection, immediately after Bongo net operation

Figure 24: Preserved zooplankton samples for estimation of biomass and community structure.

Reference

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5.8 Microbiology and biogeochemistry studies

Introduction

The oceanic waters around Antarctica and adjoining SO account for 13% of global primary productivity and play a major role in global biogeochemical cycle of carbon and nutrients (Sarmeinto and Le Quéré, 1996). The efficiency of the "carbon pump" in these waters is however debatable. Collectively, Southern Ocean waters export about 14% of the primary production (Honjo et al. 2008). Primary production in these waters is highly heterogenous- coastal and shelf waters, oceanic fronts experiencing upwelling and Marginal Ice Zones (MIZ) are more productive than the open southern ocean waters (Moore and Abbott, 2000, Fitch and Moore, 2007). Increased thermal stratification due to sea ice-melting and warming of surface waters can induce a shift in bloom species in these waters, thereby altering the efficiency of "carbon fixation". Within the Southern Ocean, the Indian Ocean sector is relatively poor in primary production (543 g C $m^{-2}y^{-1}$; Arrigo et al., 1998) but shows high microbial production (Moriarty et al., 1997).

Microbial loop and microbial remineralization processes are important biological components that regulate the carbon flux within the euphotic zone and result in outflux of carbon through respiration, thereby countering the "biological pump". Phytoplankton blooms in the Indian sector of Southern appeared to induce two distinct forms of biological responses within the bloom and adjacent HNLC waters (Jasmine et al., 2009). Moreover, the frontal zones are hotspots for microbial activity and bacterial production (Moriarty et al., 1997). However, there is little information on microbial degradation & turnover rates, organic carbon inventory (various components of dissolved (DOM) and particulate organic matter (POM)), interactions between various components of microbial loop and its role as a conduit for carbon flux.

Sediment traps are widely used to collect sinking particle/aggregates to estimate the particle flux on varying time-scales. Sediment trap samples yield valuable information on the biotic and abiotic processes that alter the nature and sinking rates of particles, biological and chemical composition, help estimate the mass-balances of various elements and can be used to reconstruct palaeoclimatic processes (Honjo et al., 2008). Both short-term and long term sediment trap studies in both Pacifica and Atlantic sectors of SO showed a strong decoupling between carbon and silica with carbon export largely in the form of siliceous diatoms. Nevertheless, in the Indian sector of Southern Ocean the physical processes including circulation patterns below the African landmass connecting the south Atlantic waters to the south Indian Ocean waters are highly complex (MacDonald and Wunsch, 1996) and its impact on the biology and sinking rates of particles in this area is key to our understanding of carbon biogeochemistry and the efficiency of the "biological pump" in these waters.

Objectives

- To study the dynamics of various components of microbial loop-Bacteria-phytoplankton interaction.
- To estimate carbon turnover rates in the euphotic layer- organic carbon uptake rates.
- To establish organic carbon inventory- molecular characterization and size fractionation DOM and POM- Distribution and characterization of siderophores, carbohydrates and proteins.
- To estimate the total flux and various components of particulate matter in the study area over seasonal and yearly time-period- Sediment trap mooring.

Materials & Methods

Seawater samples for different microbiological and organic carbon parameters were collected from different stations ranging from various fronts and polar waters (**Figure 25**). The details of the sampling stations and depths is described in **Table 21**.

Organic carbon inventory- Seawater samples were collected from various depths upto 1000 m and filtered through preashed GF/F filters. The particulate samples collected on these filters shall be analyzed for particulate carbohydrates and proteins. Also, the filtrate were analyzed for dissolved carbohydrates and proteins

Dissolved Proteins - Dissolved proteins were analyzed following Bicinchoninic acid assay (BCA). One ml of the 0.2µm filtered seawater was taken in acid cleaned test tubes and one mL of BCA mixture was added and incubated in heating block at 80ºC for 1 h. The reaction mixture was then cooled and measured spectrophotometrically at 562 nm (Bernner *et. al.,* 1995).

Dissolved monosaccharides (MCHO) - One ml of filtered seawater was reduced to alditols and complexed with 3-methyl-2-benzothiozolinone hydrazine hydrochloride (MBTH) and $FeCl_3$ and measured spectrophotometrically in presence of acetone at 630 nm (Bhosle *et al.,* 1998).

Siderophore distribution-Large volume seawater (100 L) samples were collected at select stations (7 stations) from surface, DCM and 200 m depths and filtered through Tangential Flow Filtration (TFF) system to fractionate the samples into GF/F filtered fraction, 0.2 µm filtered fraction, > 1kDa fraction and < 1kDa fraction. The <1 kDa fraction was then extracted with XAD-16 resin and eluted in methanol. The eluted fraction will be analyzed for siderophore characterization in the laboratory (Velasquez *et. al.,* 2011). All the other fractions will be analyzed for DOM chemistry.

Bacterial abundance, diversity and uptake experiments - At select stations (**Table 21**), seawater samples were collected from surface, deep chlorophyll maxima (DCM) depth and 200 m depth, filtered through 0.2 µm filters and kept frozen for bacterial diversity analyses . Similarly, bacterial heterotrophic carbon uptake experiments were conducted at specific stations using water samples from surface, DCM, 100 m and 200 m depths . The samples were incubated for 4 h at 19 ± 2°C after inoculating with ^{14}C-labeled glucose and the incubation was terminated using formalin. The samples were then filtered through 0.2µm filters and filters transferred into scintillation vials. The samples were kept frozen and shall be analyzed using scintillation counter (Signori *et al.*, 2014).

Bacteria-phytoplankton interaction

Onboard incubation experiment was carried out to investigate the effect of siderophore and dissolved iron on phytoplankton growth . In order to carry out this experiment, 100 L of surface seawater from station #19 (Table 1; SST of 0ºC) was first filtered through 200µm mesh to remove swimmers and concentrated to 1 L by passing through 10µm nylon mesh. This concentrated phytoplankton sample was then used as an inoculum for the experiment. The medium for the experiment was 0.2µm filtered seawater and siderophore extracted seawater (Sidero '-') which was amended with acidified $FeCl_3$ (1 µM final concentration). The medium (750 ml each) was then distributed in 1 L polycarbonate bottles for the experiment. A similar set of medium was prepared without any acidified iron amendment. To both these sets of medium, 50 ml of the inoculum was added. Controls were kept with the same combination but without inoculum. All these bottles were kept in an incubation tank placed on deck through which surface water was continuously passed to simulate natural temperature and ambient light conditions. Sub-sampling was carried out every day for bacterial abundance and phytoplankton growth using FRRF. The experiment was terminated after 8 days when the ambient SST was 3ºC (PF2).

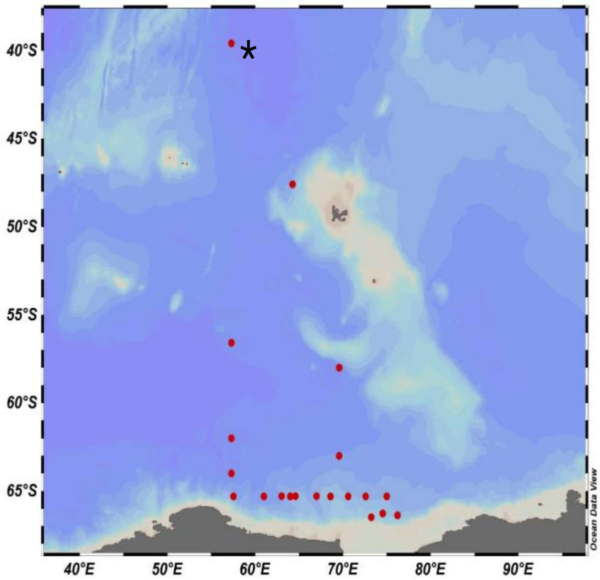

Figure 25: Study area map showing various locations wherein seawater samples were collected. Star symbol indicates mooring location.

Table 21 Details of sampling stations including the types of samples collected from different depths. Samples were collected from surface, 10m, 30m, 50m, DCM, 75m, 100m, 200m, 500m and 1000m. Samples for Bacterial diversity, siderophore and ^{14}C-uptake experiment from surface, DCM, 100m and 200m only.

CTD No	Latitude (S)	Longitude (E)	DOM	POM	TBC	Bacterial Diversity	Siderophore	^{14}C-uptake
1	39°59.76	57°30.05	50ml	6L	15ml	0	200L	-
2	47°59.84	64°27.91	50ml	6L	15ml	30L	0	-
3	54°02S; 68°10.21E Station was cancelled due to bad weather							
4	58°00.00	69°59.57	50ml	6L	15ml	0	300L	400ml at each depth
5	63°00.88	69°59.24	50ml	6L	15ml	0	0	-
6	65°30.10	75°00.52	50ml	6L	15ml	30L	0	-
7	65°30.14	72°59.73	50ml	6L	15ml	0	0	-
8	66°49.37	73°22.94	50ml	6L	15ml	0	300L	400ml
9	66°28.95	74°54.20	50ml	6L	15ml	0	0	-
10	66°38.81	76°22.81	50ml	6L	15ml	30L	300L	400ml
11	65°30.03	70°59.55	50ml	6L	15ml	0	0	-
12	65°30.08	68°59.75	50ml	6L	15ml	0	0	--
13	65°29.82	67°00.26	50ml	6L	15ml	0	0	-
14	65°29.84	64°59.63	50ml	6L	15ml	0	0	-
15	65°30.19	64°00.10	50ml	6L	15ml	30L	0	-
16	65°29.90	63°00.15	50ml	6L	15ml	0	0	-
17	65°30.05	61°00.21	50ml	6L	15ml	0	0	-
18	65°31.85	57°51.10	50ml	6L	15ml	30L	300L	400ml
19	64°00.12	57°30.12	50ml	6L	15ml	0	0	-

20	62º00.13	57º29.98	50ml	6L	15ml	0	0	-
21	56º59.24	57º30.45	50ml	6L	15ml	30L	300L	400ml
22	51º00.00	57º30.00	50ml	6L	15ml	30L	300L	400ml
23	47º30.00	57º30.11	50ml	6L	15ml	30L	300L	-

Preliminary results:

The samples for POM, DOM, bacterial abundance, diversity, siderophore extraction and experiments were stored at 4ºC and -20ºC, as per requirement. Nevertheless a few dissolved protein and monosaccharide (MCHO) samples could be analyzed on-board.

Dissolved proteins and MCHO- Dissolved protein concentrations showed distinct spatial variability both in surface and in depth. Surface protein concentrations varied from 2µg mL^{-1} (off Prydz bay) to 14.5µg mL^{-1} off Kerguelen. The entire water column off Kerguelen was enriched in dissolved proteins while waters off Prydz bay had less concentrations. Depth-wise accumulation of dissolved proteins was observed off Prydz bay waters (up to 200 m) while off Kerguelen, protein concentrations peaked at DCM and did not show any specific trend below with depth. At STF station, protein concentrations accumulated up to 100m and decreased thereafter.

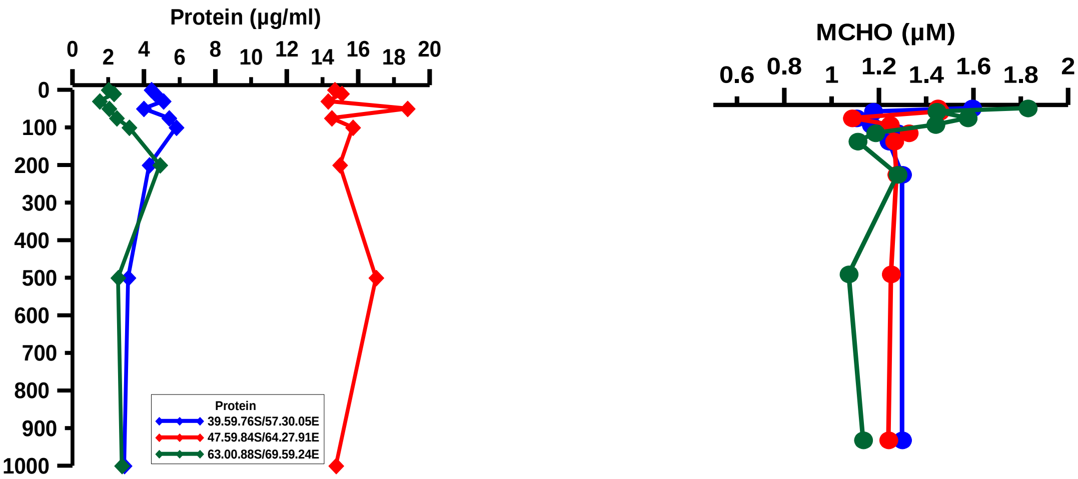

Figure 26. Vertical profiles of (a) Dissolved proteins (µg mL^{-1}) and (b) dissolved monosaccharides (MCHO, µM) at STF (39.59S;57.30E), off Kerguelen (47º59'S; 64 27'E) and off Prydz bay (63 S; 69 59'E) during SOE-10.

Dissolved MCHO concentrations in Figure 26, did not show much variation both spatially and with depth. Overall, MCHO concentrations ranged from 1.82 to 1.04µM, generally decreased with depth up to 100m and did not show much variations thereafter. Unlike proteins, surface MCHO concentrations were higher off Prydz bay and lowest off Kerguelen waters.

Expected outcome

Results from POM and DOM analyses shall help in understanding the diagenetic state and source of OM in the study area. The siderophore study shall help in understanding the nature and concentrations of these iron-chelating compounds and their role in biogeochemical process and primary production. Diversity data shall give insights in to the microbial population and their links to OM chemistry, primary production and phytoplankton diversity. Uptake experiment data shall throw light on the heterotrophic activity of bacteria and their contribution to the microbial loop. Siderophores are known to increase the bioavailability of iron for phytoplankton growth. The on-board incubation experiment may help in revealing the effect of siderophore and siderophore producing bacteria in phytoplankton growth.

Retrieval of sediment trap mooring

A sub-surface sediment trap mooring was deployed at 40º11’ S and 58º30’ E location (Fig. 1). The sub-surface mooring is at a depth of 5133 m and the same shall be retrieved during this expedition. The location was reached on 16/12/2017 afternoon and immediately attempts were made to locate the mooring using a deck unit attached to a transponder.The deck unit transponder onboard was used to send an ‘enabling’ signal specific for each acoustic releaser attached to the mooring line. By nightfall, the mooring was located and preparations were done for retrieval of the mooring. Upon receiving the response from the releaser, “release” command was given and in response, 5 pings at 200 ms interval was received indicating the released state of the mooring. Thereafter, the whole night was spent in locating the buoy to which a flasher and a satellite beacon were attached. The next day, attempts were made to locate the mooring and was found to have drifted slightly from its original location, indicating that the mooring was released but had not surfaced. All the operations and the settings of the deck unit and the releasers were counter checked with OEM and it was confirmed that there was no error on operation of the deck unit. In the event of no buoy surfacing and lack of any major drift, a decision of taken to revisit the site on the return journey.

The site was reoccupied on 27/01/2018 during the return journey. The same exercise was repeated to locate the mooring but we received no response. Subsequently, 30 hours of trawling was carried out using 2700 m long cable line having 5 grapnel hooks attached at various depths to 40 m long chain at the end of the cable. The trawling was carried out non-stop but did not yield any success. **It is** concluded that the mooring did not surface properly and has drifted with currents. Hence the mooring is deemed missing.

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5.9 Study of paleoclimatology and paleoceanography of the Indian Sector of the Southern Ocean

Introduction

The Southern Ocean influences earth climate by storing and transporting large amount of heat and carbon dioxide (CO_2) between atmosphere and oceans. Southern Ocean had influenced climate by sequestering CO_2 during the glacial periods and releasing it during the interglacial periods. In the near future, the Southern Ocean is projected to absorb excess anthropogenic CO_2, which may decrease pH of its water masses and affects aragonite-calcite saturation levels. In spite of Southern Oceans role in modulating present and past climate, the ocean-atmospheric and glacial-interglacial carbon dynamics were not studied in detail. The proposed project aims to specifically fill this knowledge gaps by generating high resolution multiproxy reconstructions of paleoproductivity, paleotemperature, paleosalinity and oceanic circulation patterns in the key regions of the Southern Ocean regions. The present and past investigations in the Southern Ocean offer opportunity to study carbon cycle functioning in the present and during the glacial-interglacial periods. The interpretation of carbon sequestering mechanism in the past and in the near future will provide better insights about air sea carbon linking in the past and potential influence of ocean acidification in the future.This project is designed to test key processes related to Southern Ocean biogeochemistry and air-sea interaction during the present and past using coccolithophores, foraminifera and diatoms. The movement of oceanic fronts, productivity, surface-ocean stratification, calcareous v/s siliceous production during the past; and coccolithophore, foraminiferal ecology, biogeography, calcification, relationship with pCO_2 in the present will be also assessed. The probable effects of decreasing pH on coccolithophore and foraminifera calcification and functioning, coccolithophore size variability and its relationship with physic-chemical characteristics and probable explanations for their increasing southward expanse will be also carried out. This project, with systematic approach, by unravelling changes in paleoproductivity, dissolution, paleotemperature, paleosalinity in the present and during the glacial-interglacial cycles , which would improve our capability to predict future changes in the Southern Ocean.

Objectives

Collection of five sediment cores to study

- Late Quaternary climatic variability and paleoproductivity in the Indian sector of the Southern Ocean utilizing microfossils and nannofossils

- Late Quaternary oceanic frontal variability, paleotemperature and paleosalinity reconstruction utilizing coccolith and diatom abundance and morphometric variations.

Analysis of water samples to assess

- Extant coccolithophore ecology and biogeography and understanding their role in marine biogeochemical cycles

Materials & Methods

Collection of Sediment cores

Three sediment cores were collected from the Indian Sector of the Southern Ocean and kept in -20^{o}C for further analysis. These samples will be analyzed for coccolithophores and diatoms using method described by Flores and Sierro (1997). Diatom morphometry will be studied to reconstruct paleotemperature using transfer function. The δ18O, δ13C, Ca/Mg and B/Ca of foraminifera will be analyzed to reconstruct past climatic changes.

Water sample collection and analysis

For coccolithophores,189 Water samples were collected at (9 depths x 21 profile stations) and filtered on 0.8 micron and 3 micron polycarbonate nuclepore filters and 0.45 micron cellulose filters.Identification, quantification and measurement of key coccolithophore species will be carried out using Polarizing and Scanning Electron Microscope(SEM).

Preliminary results

All collected samples were persevered as necessary and kept under respective temperature for further analysis in the NCAOR laboratory as due to non-availability of SEM and other instruments on board. Therefore the result outcome will be discussed later after detail analysis of samples

Table.1: Shows the detail of sample collections and locations

Sr. No	Sampling type	No of samples and depths	Parameters
1	Vertical profiles	22 profiles X 9 depths (198 samples)	Coccolithophores, trace metals, silicon isotopes, polysaccharides etc
2	Surface water samples	50 surface water samples	Coccolithophores, phytoplankton, Chlorophyll, HPLC, POC, Nutrients, Major ions, Silicon Isotopes, Major Ions, Trace Metals, pH, temperature, Salinity
3	Sediment cores	Three (core 1- 15cm, core 2- 3.7m, core 3- 3.75m)	To study paleoceanography using coccoliths, diatoms, silicoflagellates and foraminifera
4	Time Series	One (4 observations)	Coccolithophores, trace metals, silicon isotopes, polysaccharides etc

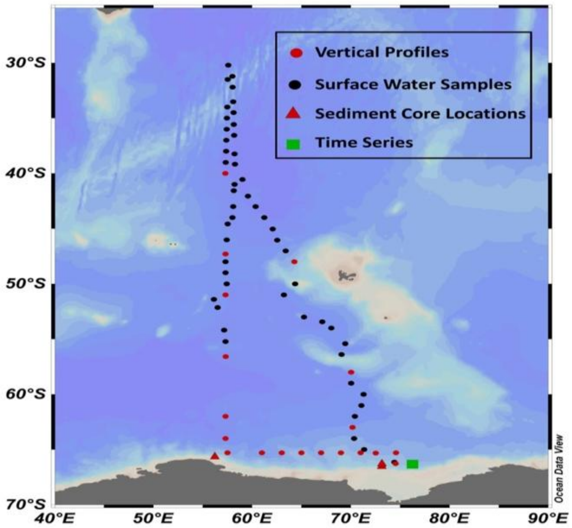

Figure 1. Map showing sampling locations during 10th SOE

Expects outcomes

This study will help to understand coccolithophore and diatom ecology and biogeography of the Indian Sector of the Southern Ocean. It will also provide insights about coccolithophores role in the past climatic alterations by reconstructing high resolution multiproxy records of the sediment cores. The benthic foraminifera (δ18O, δ13C, Ca/Mg) and diatoms proxies (absolute and relative abundance, morphometric studies) study would help to understand the present and past climatic system.

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5.10 Quantitative reconstruction of past Southern Ocean and Southern Indian Ocean climate and its teleconnection with the Indian Monsoon

Introduction

The variability of the Indian Summer Monsoon is of great interest to the inhabitants of the South Asian countries due to its direct relationship with the food security of the region. Monsoon manifests itself as a northward migration of the ITCZ from equator to upto 25°N. Although there are a number of meteorological features associated with the ISM, such as the North-South surface pressure and temperature gradient, low level south-westerly jet, upper level easterly flow and the monsoon trough to name a few, the North-South gradient of tropospheric temperature (TTG) is now widely accepted as a primary driver of the ISM (Xavier et al., 2007). Tropospheric heating helps maintain upper level divergence which leads to augmented convergence and uplift of moisture at the lower level. Some of the other factors such as the land-ocean thermal contrast ceases once the Monsoon attains its peak, but TTG continue to remain a quasi-permanent feature throughout the season and is therefore a necessary condition for season-wide precipitation. TTG as a primary driver is also evident from the role it plays in the way external factors such as ENSO, NAO and AMO affect the Indian Monsoon (Burns et al., 2003; Goswami et al., 2006; Krishnamurthy and Goswami, 2000). An increased tropospheric temperature gradient is found during years with intense Monsoon activity whereas a weaker gradient exists during the periods of below normal activity. Although factors such as the NAO can directly affect the TTG, and thus the ISM, a majority of them do so by modulating the convective activity as well as the SST of the equatorial Indian Ocean (EIO). As such, over the instrumental period, ISM and EIO SST have shown a tendency to remain out of phase with each other (Roxy et al., 2015). A high frequency Southern Ocean-ISM teleconnection has also been suggested via Indian Ocean SST modulation by the Southern Annular Mode (SAM), the greatest mode of climate variability in the southern high latitudes.

Objectives

- To quantitatively estimate the latitudinal variation in the past SST in the Southern Ocean and Southern Indian Ocean and explore its teleconnection with Indian monsoon.
- A part of the problem in understanding Polar-Monsoon teleconnection lies in the non-quantitative nature of most the existing records.
- Here, our emphasis would be on quantitative estimation, primarily of the SST using Mg/Ca of the foraminifera shells as a direct proxy of temperature.

- Past SST data for southern Indian Ocean, southern mid-latitude and southern high-latitude will be generated for this purpose and a comparison would be drawn to investigate the influence of southern latitude SST variability on the Indian Monsoon.
- The SST data will be further delineated from the oxygen isotope data of the foraminifera to get precise salinity changes related to the past hydrographic variability.

Materials & Methods

Sediment cores were collected from locations as shown in the table below. The coring was done by a gravity corer (4 m in length, diameter of 123 mm and a total weight of 600 kg) at water depths less than 3500 m. (Table 1)

Table.1 Core sampling collections

Date	**Latitude (S)**	**Longitude(E)**	**Depth (m)**	**Length of core (m)**
7/01/2018	$66^{o}27.25$	$73^{o}18.38$	1855	3.7
14/01/2018	$65^{o}32.23$	$56^{o}50.25$	2048	3.7

The collected cores will be transported to NCAOR at -20 ^{o}C. They will then be sub sampled at 1 cm interval. The samples will then be analyzed with IRMS for stable isotope composition (oxygen, carbon and nitrogen isotopes), and ICP-OES for trace element ratios (Mg/Ca, Sr/Ca etc.).

Surface water samples were collected for approximately every half a degree transect between 30^{o}S and 67^{o}S. (Table 2) These samples will be analyzed for oxygen isotope composition to establish Oxygen Isotope-Salinity relation in modern Southern Ocean waters.(Table 2)

Sl No.	No. of Stations	Type of sampling	Location
1	109	Surface water	30^{o}S to 67^{o}S along the SOE-10 cruise track

Expected outcome

All facilities required for the proposed geochemical investigation of sediment cores and water samples are housed in the Marine Stable Isotope Lab and the Paleothermometry lab at NCAOR. Radiocarbon dating will be done outside NCAOR. Mg/Ca based paleothermometry will be carried out using the LA-ICP-OES. Sedimentary Organic Matter (SOM) and its carbon and nitrogen isotopic composition will be analyzed using EA-IRMS. Carbon and Oxygen isotopic composition of microfossils (foraminifera) will also be analyzed in with the help of IRMS.

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5.11 Study of Mercury and Methyl mercury in the lower food-web of Indian sector of Southern Ocean

Introduction

Methylmercury (MeHg) is a notorious bioaccumulating neurotoxin, which causes brain and neurological damage in humans and has detrimental effects on wildlife (Wolfe et al. 1998; Clarkson and Magos 2006). Uptake at the base of the food chain is influenced by mercury (Hg) and MeHg concentrations and speciation (complexation) in the water column (Mason 2002; Moye et al. 2002; Chen et al. 2008). Passive Hg and MeHg uptake into phytoplankton is upheld as an essential intake mechanism (Mason et al. 1996; Mason 2002; Pickhardt and Fisher 2007), while active uptake of MeHg has been recognized in freshwater species (Moye et al. 2002; Le Faucheur et al. 2014).

Exposure to methylated mercury (MeHg) from fish consumption and the associated adverse health effects in humans are a global concern. Inorganic mercury is released from both anthropogenic and natural sources, enters the marine ecosystems via river discharges and atmospheric deposition and is converted to MeHg in ocean water column and estuarine, coastal and shelf sediments. Seawater MeHg concentrations are magnified by a factor of 10^4 to 10^5 in primary and secondary producers and by 10^6 or more in predatory fish. Phytoplankton and zooplankton form the base of this food chain. They critically determine the amount of MeHg that is available for transfer to higher trophic levels.

Availability of MeHg in planktons is influenced by a number climate and ecological changes. Increased primary productivity can lower biological MeHg concentrations in several ways including: (1) reduced MeHg bioavailability in seawater due to greater partitioning to suspended particles, (2) altering the size distribution of phytoplankton communities toward larger organisms, thereby lowering the cell surface area available for MeHg uptake, and growth dilution of zooplankton that consume high quality algae. However, smaller phytoplankton have higher MeHg concentrations than larger ones and oligotrophic waters may have a higher abundance of pico- and nano-phytoplankton (picoplankton: 0.2-2 μm; nanoplankton: 2-20 μm, and microplankton: 20-200 μm). Additionally, uptake of MeHg into phytoplankton is determined by a number of other factors such as dissolved organic carbon (DOC), and the surface area to volume ration. Additionally, higher concentration of MeHg has been observed in the hypoxic zones in the oceans. In this work, we aim to observationally assess these factors that determine the uptake of MeHg into phytoplankton and zooplankton in the Southern Ocean. Accumulation of monomethylmercury (MMHg) by plankton is a key process influencing concentrations of this toxic mercury species in marine food webs and seafood. We focusing to examine bioaccumulation and biomagnification of MMHg in microseston and fraction of zooplankton on the Indian sector of southern ocean.

Objectives

- What are the level and general distribution of $Hg_T$and MeHg concentrations in the waters of the Southern Ocean, and is there any indication for sources and sinks?
- What re the characteristics of the Hg speciation in the waters, which may shed light on Hg cycling specificity of the SO?
- Observationally quantify the bioaccumulation of mercury and MeHg in the lower food chain (phytoplankton and zooplankton) of Southern Ocean
- Evaluate the relationship between phytoplankton MeHg and the contributing factors: seawater MeHg, DOC, phytoplankton size fractions and growth rates.(in a transect with variable waters (e.g., Antarctic bottom waters, Circumpolar Deep Waters, and Antarctic Intermediate Waters)
- Assess the possible implications of ecosystem and climate change by observing the multi-year variability

Materials & Methods

The sampling locations are presented in Table 22 these sampling methods was followed recommended GEOTRACES (www.geotraces.org) protocols as closely as possible. Sea surface water sample was collected manually with polypropylene bucket and water column-profile samples were collected using externally closing, Teflon-lined Niskin sampler, samples for total mercury (Hg_T) and methylated mercury species (MeHg). Water were immediately withdrawn into acid-cleaned Wheaton Wide-Mouth Bottles, following ultraclean sample handling protocols within an ISO class-100 clean air laboratory container. Total mercury Samples were acidified with Brominmonocloride (BrCl) (0.2%, v/v Brooksrand), and methyl mercury samples ware acidified with *0.2% (v/v) H_2SO_4 is preferred to avoid exceeding the optimal chloride concentration (*Jennifer *L. Parker, and Nicolas S. Bloom. 2004) h*ermetically sealed, double-wrapped in polyethylene bags, and kept in the dark at +4°C for analysis in the home laboratory (Indian Institute of Technology Hyderabad).

Zooplankton samples were collected at 25 locations in surface waters with bongo net (mesh size 200µm) these sampling locations are mentioned in Table 22. Zooplankton net was deployed at in surface (0-2m) water and dragged 15 mintues with 3konts ship speed initial and final water flow meter readings was noted in every location. Zooplankton sample was collected immediately into acid-cleaned tarson HDPE Spin win Conical Bottom Tube (Polypropylene) *h*ermetically sealed, double-wrapped in polyethylene bags, and kept in the dark at -20°C for analysis in the home laboratory (Indian Institute of Technology Hyderabad).

Surface water was used for collecting the phytoplankton it was took from the bucket sampling. Phytoplankton were obtained by filtering the seawater through polycarbonate filter paper size of 0.75µm. Larger particulate material was excluded by initially passing water through a 200µm mesh. These filer papers collected in petri dishes and wrapped in polyethylene bags, and kept in the dark at -20°C for analysis in the home laboratory (Indian Institute of Technology Hyderabad)

Table 22. Sampling locations Y: Sampling as done N: Sampling not done

			Mercury and methyl mercury samples analysis		
Sl.NO	**Latitude (^{0}S)**	**Longitude (^{0}E)**	**Water Sample depth (m)**	**Zooplankton sample**	**Phytoplankton Sample**
1	39.59	57.29	0	N	N
2	43.07	60.39	0	N	N
3	43.35	60.59	0	N	N
4	48.03	64.20	0	Y	N
5	54.01	68.16	0	N	N
6	58.01	70.11	0	Y	Y
7	63.00	70.00	0	Y	Y
8	65.32	74.55	0	Y	Y
9	65.32	72.50	0	Y	Y
10	66.49	73.22	0	Y	Y
11	66.28	74.54	0	Y	Y
12	66.30	76.00	0,30(DCM),75,500, 900	Y	Y
13	66.35	76.22	0	Y(TS)	Y
14	66.57	75.15	0	N	N
15	65.30	70.59	0	Y	Y
16	65.30	70.00	0	N	N
17	65.30	68.59	0	Y	Y
18	65.30	68.00	0	N	N
19	65.29	67.00	0	Y	Y
20	65.30	66.00	0	N	N
21	65.29	64.59	0	Y	Y
22	65.30	64.00	0	N	N
23	65.27	62.53	0 (triplicate)	N	N
24	65.30	61.59	0	N	N
25	65.30	61.00	0	N	N
26	65.30	60.00	0	N	N
27	65.30	58.01	0	N	N
28	65.31	57.51	0,50,80(DCM),500,1000	Y	Y
29	64.00	57.30	0	Y	Y
30	62.00	57.31	0(duplicate)	N	N
31	58.54	54.46	0	N	N
32	56.59	57.30	0,75, 60(DCM),500,1000	Y	N
33	51.58	56.29	0	N	N

36	51.00	57.30	0,69(DCM), 75,500,1000	Y	N
37	48.00	57.30	0	N	N
38	47.29	57.30	0,50(DCM), 75,500,1000	Y	N
39	48.00	57.30	0	N	N
40	39.59	57.30	0,39(DCM), 75,500,1000	Y	N
41	39.59	57.30	40L Water sample collected for Mercury Photoreactions study.		

Preliminary results

The collected samples were kept under the required temperature and transported to the NCAOR laboratory through reefer container. The further analysis of sample would be interpreted to understand the role MEHG to the biogeochemical cycle in the Indian sector of the Southern Ocean.

Expected outcome

This work is expected to add a major vast database on the occurrence of Hg and MeHg in Southern Oceans. As mercury science is fast advancing, we will provide a timely input to the ever expanding database from a location that has not normally been studied. In addition, we will contribute to fundamental knowledge behind the uptake of MeHg into the base of marine food webs. Finally, we will be able to analyze multi-year variability of, and interdependence between MeHg and water chemistry, and may be able to project on the impacts of climate and ecosystem change on MeHg bioaccumulation in marine water.

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5.12 Screening of microorganism from Indian sector of Southern Ocean for antimicrobial activity with their molecular characterization

Introduction

The search for microbes with antimicrobial activity has gained importance in recent years due to growing worldwide concern about alarming increase in the rate of infection by antibiotic-resistant microorganisms. To achieve novel antimicrobial compounds and the opportunity to access geographically diverse sampling areas and different ecological niches are of fundamentals importance. Southern Ocean, which harbors rich microbial diversity, seems to have a promising future in the development of novel biologically active substances. This is a less characterized environment regarding microbial diversity and ecology. Marine organisms lives in complex habitat and exposed to extreme conditions such as pressure and temperature. Under these extreme conditions they produce wide variety of secondary metabolites that are biologically active such as polysaccharides, polyunsaturated fatty acids (PUFAs), antioxidants, sterols, proteins, pigments and anti-cancerous activity (Lordan et al., 2011). Our proposed project aims at isolation and screening of microorganism from different fronts of southern ocean and exploring their potential as antimicrobials. This study would also enhance our knowledge of microbial diversity and ecology of Indian sector of southern ocean.

Objectives

- To screen antimicrobial/antibiotic activity of microbes isolated from Indian Sector of Southern Ocean
- Characterization (Morphological, Biochemical, and molecular) and identification of novel antibiotic producing strain
- Structural elucidation of antibiotic/bioactive compound through spectroscopic techniques
- Complete genome sequencing and annotations of industrially relevant antibiotic producing strain

Materials and methods

Bacteriological Media (HI-Media) Modified nutrient agar and Peptone water prepared in sea water were used forenumeration of total viable bacterial population; Modified nutrient broth prepared in sea water was used for culturing of bacteria by direct inoculation method. Similarly, soybean casein digests broth, chloramphenicol yeast glucose agar (CYGA), Potato dextrose agar were used for isolation and fungal population. BG-11 medium was also used for culturing cyanobacteria and other microalgae. Sterilized disposable plastic petri-dishes (90 mm, Hi-Media) were used for the experiments. On board, sterilization of sampling bottles, media, reagent, filtration assembly and other material were carried out using vertical autoclave.

Samples Collection

Samples were collected from different temperature based zone and fronts such as Sub-tropical Front, Sub-antarctic front, Polar front 1 and Polar front 2 including one time series at Polar fronts. Sea water samples were collected in sterilized bottles from different depths using CTD operations (Table 23). Algal blooms were collected from five Stations using Bongo net operation. Sediment sample from catchers of corer of different size were collected from three stations through gravity corer operations. Sediment samples were taken with help of sterile spatula and immediately diluted and inoculated in sterile selective media for cultivation of microbes. One set of samples were stored at -20°C for further study at main Laboratory.

Table 23. Sampling and location Details

1.	Station No	Latitude	Longitude	Sample category	Depths (in meter)
2.	1	39°59' S	57°30' E	Sea water	0,200,500,1000
3.	2	47°59' S	64°27' E	Sea water	0,200,500,1000
4.	3	54° 02' S	68° 10' E	Sea water	0,200,500,1000
5.	4	58° S	69° 59' E	Sea water	0,200,500,1000
6.	6	63°00' S	69° 59' E	Sea water	0,200,500,1000
7.	7	65° 30' S	70° E	Sea water	Surface sampling
8.	9	65°30' S	72° 59' E	Sea water	Surface sampling
9.	11	66°49' S	73° 22' E	Sea water, sediment	Surface sampling, 509m
10.	13	66°28' S	74° 54' E	Sea water	Surface sampling

11.	**15 TS-1**	66°38' S	76°22' E	Sea water, Algal Blooms	Surface sampling
12.	**TS-2**	66°33' S	76° 25' E	Sea water, Algal Blooms	Surface sampling
13.	**TS-3**	66°24' S	76° 22' E	Sea water, Algal Blooms	Surface sampling
14.	**TS-4**	66° 34' S	76°18' E	Sea water	Surface sampling
15.	**TS-5**	66°39' S	76° 06' E	Sea water	Surface sampling
16.	**TS-6**	66°38' S	76° 16' E	Sea water	Surface sampling
17.	**16**	66° 27' S	73°18' E	Sediment	1855
18.	**17**	65°30' S	70°59' E	Sea water	Surface sampling
19.	**19**	65° 30' S	68° 59' E	Sea water	Surface sampling
20.	**21**	65°29' S	67° E	Sea water	Surface sampling
21.	**23**	65° 29' S	64° 59' E	Sea water	Surface sampling
22.	**25**	65°29' S	63° E	Sea water	0,120,150,200,500,750,1000,1500,2000
23.	**27**	65°30' S	61° E	Sea water	Surface sampling
24.	**29**	65°33' S	56° 50' E	Sediment	2048
25.	**30**	65°31' S	57° 51' E	Sea water, algal blooms/diatoms	0,200,500,1000,2000
26.	**31**	64°S	57° 30' E	Sea water	0, 4000
27.	**32**	62° S	57° 29' E	Sea water	0, 4000
28.	**33**	56° 59' S	57° 30' E	Sea water	0,200,500,1000
29.	**34**	51° S	57° 30'E	Sea water, algal blooms	0,200,500,1000
30.	**35**	47°29' S	57° 30' E	Sea water	0, 50, 100, 200, 500, 1000, 1500, 2000, 4000
31.	**36**	39°19' S	57°30' E	Sea water	0, 50, 120, 200, 500, 750, 1000, 1500, 2000, 3000 4000

Preliminary Isolation and Enumeration of Culturable Bacteria

Three liter of sea water samplewere filtered through sterile 0.22 µm pore size membrane filter using sterile filtration assembly and vacuum pump. Membrane filter then washed using 3 ml of autoclaved water and then inoculated to modified selective media for culturing of marine microbes. To obtain bacterial culture, 1 ml of membrane washed suspension was transferred in to modified nutrient broth. 0.1 ml of aliquot from membrane washed suspension was spraded on nutrient agar plates forenumeration of cultrable bacterial population. Incubation was done at 20 °C. Bacterial Culture from broth tubes and different colonies from agar plates were preserved in 25% Glycerol and kept at -20 °C for further detailed study.

5.13 Preliminary Isolation and Enumeration of Culturable Fungi

For isolation and enumeration of fungi, 0.1ml of membrane washed suspension spraded on sterile modified chloramphenicol yeast glucose agar (CYGA) Potato dextrose agar plates. Plates were incubated at 20^{0}C for 10 days. Fungal colonies observed on the plates were counted and individual colony was taken through inoculating loop and sub cultured on CYGA slant. Slants were preserved in sterile paraffin oil for further study

Isolation of Algae

Only surface sea water samples were used for the cultivation of microalgae including cyanobacteria.1 ml membrane washed suspension wasinoculated in Sterile BG-11 broth and incubated at 20°C at 12 hours dark and light with manual shaking. Algal blooms samples collected through bongo operation were also studied using above method. Microscopic observation of algae/microalgae/cyanobacteria was done using light microscope (Olympus-CKX31). Growth observed in broth flask then preserved in 25% glycerol for further study.

Preliminary results

Bacterial colonies observed on agar plates were manually counted and recorded. Different colony based on their size and shapes picked, inoculated in fresh media and then preserved in 25 % Glycerol (Figure 26). Similarly, Bacterial suspension/culture observed in nutrient broth tubes was preserved in 25 % Glycerol. Further sub culturing will be done at main laboratory in order to obtain pure culture of bacteria for detailed study. Presumptive fungal and yeast colonies were preserved in sterile paraffin oil. Presumptive cells of micro-algae were observed under microscope. Algal blooms and algal growth suspension were preserved in sterile glycerol for further identification and characterization at main Laboratory.

Expected Outcome

- ❖ The study would provide some novel antimicrobial compounds (Antibiotics) for medicinal purpose
- ❖ Novel strains of Southern Ocean microorganisms would also be utilized for other biotechnological applications

- ❖ New antimicrobial compound identified could become a product of commercial value and it could also become a base molecule for synthesis/development of new similar/derivative broad spectrum antibiotics.

- ❖ Patents, technology transfer and industrial collaboration would further support for the project/venture

- ❖ Complete genome sequencing and its annotation would add up in the knowledge database

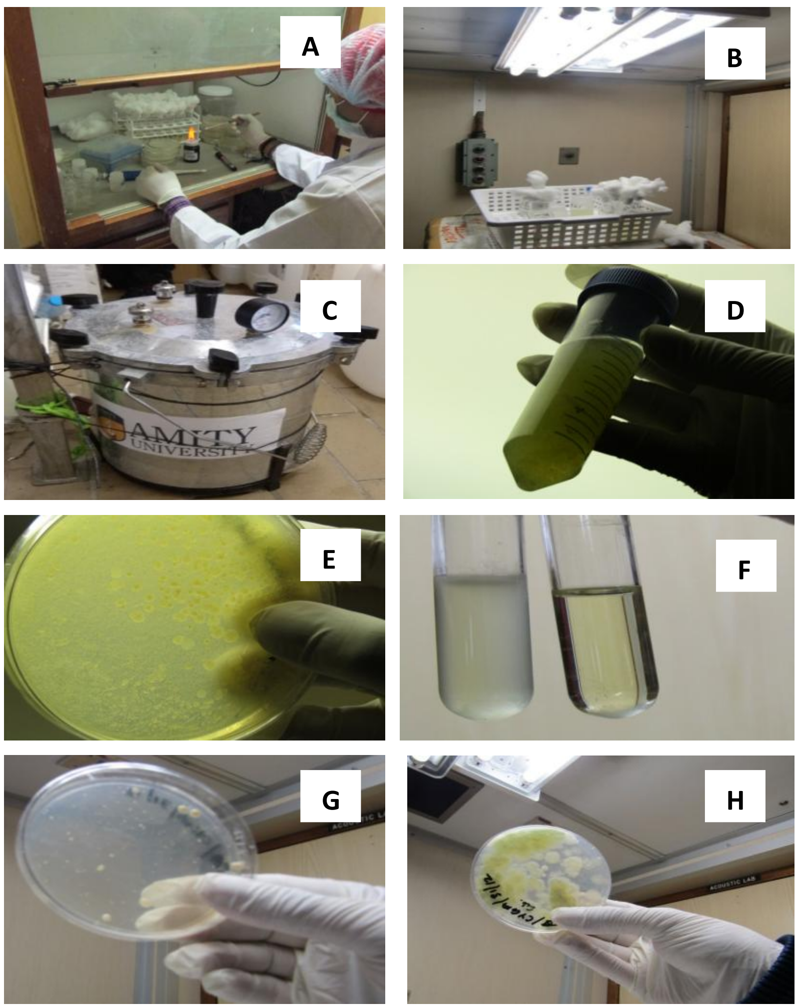

Figure 26: Onboard culturing of marine microorganisms: A: Inoculation bench; B: Photo incubation facility; C; Vertical Autoclave for sterilization; D: Presumptive algal growth in selective media; E: Bacterial colonies on Nutrient Agar Plates; F: Tube1: Showing bacterial turbidity in selective broth, CTube-2: Media control; G: Presumptive yeast colonies on modified chloramphenicol yeast glucose agar (CYGA) plates; H: Presumptive fungal colonies on CYGA media plates

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5.14 Study of Cephalopods in South Indian Ocean and Indian sector of Southern Ocean

Introduction

Cephalopods (Mollusca: Cephalopoda) are playing a key role in many marine ecosystems including south Indian Ocean (SIO) and Indian sector of the Southern Ocean (ISSO) both as predators and prey (Clarke, 1996; Piatkowski et al., 2001) and represent one of the most important commercial marine resources (Arkhipkin et al., 2015) in the . The Cephalopods abundance in SIO, ISSO and Antarctic waters is very poorly known. Cephalopods resources of the ISSO are considered to be distinct from other oceans with high levels of endemism in squids (Collins and Rodhouse, 2006). After the study of Silas (1968) no detailed studies have been undertaken for examing biodiversity of cephalopods from SIO and ISSO. The present status of cephalopods diversity and abundunce in the ISSO is largely unknown. Hence the studies on Cephalopods distribution, abundance in relation to oceanographic parameters are proposed.

Objectives

- Assesment of cephalopod biodiversity in SIO and ISSO with paticular referene to oceanographic parameters
- Study the age and growth of Cephalopods intend to understand distributional pattern in ISO, ISSO and Antarctic using statolith microstructure analysis.
- To investigate role of predator and prey relationship of Cephalopods in SIO and ISSO

Materials and methods

Abundunce estimation undertaken in all stations by visual observation method (Chesalin and Zuyev, 2002) for large pelagic squids. Two IKMT operations at each station, on surface and 200 m for estimate the cephalopod paralarval abundance estimation and study the diversityand spawning season(Table 24 and Figure 27).Squid samples collected from squid jigging stations during night by using different type hand jiggs (Table 24 and Figure 27).Age and growth of squids will be analyzed following standard method Arkhipkin and Shcherbich(2012).

Priliminary results

During the expedition we were conducted total of 28 observations, outof 28,7 squid jigging stations 13 IKMT stations (21 operations) and 8 zooplanton operations. Jigging operations could not be carried out on most of the nights due to no darkness, very rough seas, strong currents and winds during the cruise

Table 24. Showing the sequence of IKMT and squid jigging operations during SOE-10

Date	Location	Operation	Depth of operation
14-12- 17	40° 11.9715 S; 58°30.6071 E	Squid jigging	30 m
18-12-17	43° 02.7797 S; 60°36.0441 E	IKMT	Surface, 200 m
22-12-17	54° 00.8662 S; 68°05.2355 E	Squid jigging	30 m
23-12-17	54° 01.2610 S; 60°07.0315 E	IKMT	Surface, 200 m
25-12-17	58° 55.1184 S;70° 09.1651 E	Squid jigging	30
27-12-17	63° 01.5137 S;70°05.9277 E	Zooplankton net	Surface
30-12-17	65° 31.2114 S;74°45.7445 E	Zooplankton net	Surface
31-12-17	65°32.4400 S; 72°50.3900 E	Zooplankton net	Surface
03-01-17	66° 33.9869 S; 76°24.0868 E	Zooplankton net	Surface
04-01-17	66° 32.7294 S; 76°24.9941E	Zooplankton net	Surface
05-01-17	66° 37.2547 S; 76°07.2954 E	Zooplankton net	Surface
06-01-17	66° 39.5306 S; 76°06.2703 E	Zooplankton net	Surface
08-01-17	65° 28.9208 S; 70°56.7027 E	IKMT	Surface
09-01-17	65° 31.4615 S; 69°08.3587 E	IKMT	100 m
10-01-17	65° 29.3495 S; 66°58.2090 E	IKMT	Surface, 500 m
11-01-17	65° 30.8285 S; 64°56.6052 E	IKMT	Surface, 500 m
12-01-17	65° 46.1649 S; 62°48.1575 E	Zooplankton net	Surface
13-01-17	65° 27 7635 S; 60°57.8369 E	IKMT	Surface, 500 m
15-01-17	65° 27 6647 S; 57°50.6964 E	IKMT	500 m
21-01-17	57°00.2944 S; 57°36.2873 E	IKMT	Surface, 500 m
24-01-17	51° 04.1752 S; 57°25.2133 E	IKMT,squid jigging	Surface, 500 m
25-01-17	47°30.9025 S; 57°29.1275 E	IKMT, squid jigging	Surface, 500 m
28-01-17	40°11. 9973 S; 58°24.0242 E	IKMT, squid jigging	Surface
29-01-17	39°56.7901 S; 57°30.5863 E	IKMT, squid jigging	200 m

Abundance estimation

Pelagic cephalopod abundance observed only three stations, 47°S-57° E, 40° S-58° E and 39° S-57° E. The species observed in the stations werered flying squid *Ommastrephes bartramii* (Fig.2 A) and Antarctic flying squid *Todarodes filippovae* (Fig. 2 B). Paralarvae of mesopelagic squids collected from 65° S 66° E to 57° S 57° E identified as *Galiteuthis* sp (Fig. 2 C).

Figure 27. Showing the operations during the 10th Indian expedition to Southern Ocean/ Antarctic waters; (A) IKMT operation; (B) Zooplankton net operation, both for cephalopod paralarvae; (C) different type of jigs used for squid sample collection; (D) squid jigging

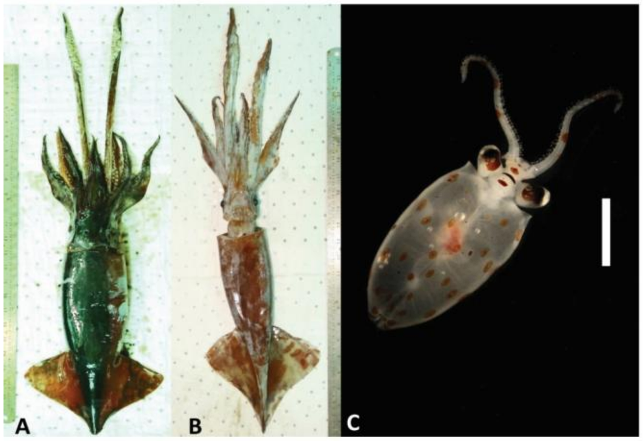

Fig.28. showing the squids collected during the expedition. (A)showing the dorsal view of *Ommastrephes bartramii*; (B) ventral view of *Todarodes filippovae*; (C) paralarvae of mesopelagic squid *Galiteuthis* sp (Scale bar= 1 cm)

Expected outcome

Biomass of cephalopods in frontal region in Southern Ocean based on visual observation method would help for understanding the distribution pattern. Age and growth rate of squids by using hard part (statolith) helps to understand the longevity and lifecycle. Paralarval cephalopods will be analysed for understanding further the spawning season and spawning ground. Cephalopods role act as a predator would show the trophic relationship in the Indian sector of the southern Ocean.

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5.15 Study of Metrology and Atmospheric Aerosols

Introduction

The variations in concentrations and composition of the most important natural aerosol systems at the global level, the marine aerosols, strongly influences the local climate and to some extent regional climate as well. The aerosols can be classified into in-situ produced and the long-range transported aerosols. Studying the associated transport mechanisms, it's known that the long range transported aerosols have potential impacts even on a global scale. Aerosols have significant impact on radiation budget, act as cloud condensation nuclei, increase cloud albedo and reduce precipitation by decreasing the effective cloud droplet size. Knowledge of aerosol properties is essential in atmospheric correction procedures in satellite remote sensing of earth's surface.

The in-situ produced aerosols are generally trapped in the lowermost layer of the atmosphere referred to as Planetary Boundary Layer (PBL) or Atmospheric Boundary Layer (ABL). The ABL dynamics play important role in transportation and concentration of aerosols.Inspite of intensive studies in this field on a global level, very less information is available explaining the role and effect of aerosols on the climate. It is important to understand the basic issues related to atmospheric aerosols with respect to their physical characteristics, composition, radiative forcing and the ABL dynamics to understand the impact of atmospheric aerosols comprehensively. Hence, with an objective of generating aerosol and atmospheric data over the Indian Sector of Southern Ocean, the 10^{th} Southern Ocean Expedition (SOE-10) was undertaken.

Objectives

In order to carry out a systematic study of the aerosols and its effects in the Indian Sector of Southern Ocean region, the following project objectives were focussed on.

1. To study spatial and temporal variability of Black Carbon (BC) mass concentration and size fraction of composite aerosols over southern ocean atmospheric domain.
2. To understand local meteorology and long range transport of atmospheric aerosols.

3. Optical characterization of aerosols by analysing spectral variation of the columnar AOD, estimation of aerosol size spectrum (α) and atmospheric turbidity (β) parameter through ship based and satellite observations and its validation.
4. To determine the chemical composition of aerosol samples collected over different locations.
5. To understand thermodynamic and stability structure within troposphere through vertical profiles of meteorological parameters over southern ocean.
6. To estimate Direct Aerosol Radiative Forcing and heating rate over southern ocean for climate studies.

In order to fulfil these objectives, the cruise objectives were outlined as follows.

1. Measurements of spatial and temporal data of Aerosol Optical Depth
2. Measurement of Black Carbon Mass Concentration over different regions across the cruise track
3. Measurements of Aerosol Differential Mass concentration at designated stations
4. Measurement of Weather Parameters both (Surface and Atmospheric) profiles such as i. Temperature ii. Pressure iii. Humidity iv. Wind Speed and Wind direction

Materials and Methods

In order to achieve the objectives given above, the following instruments were used (Table.1)

Table 25: Specifications of instruments used for on board measurements.

Instruments	Manufacturer	Technical Specifications		Measurements
Microtops II Sun photometer	Solar Light Company, Inc.	Optical channels	380, 440, 500,675, and 1025 nm	Columnar Aerosol optical depth (AOD)
Aethalometer AE-42	Magee Scientific, USA	Optical channels	370, 470, 520, 590, 660, 880 and 950 nm.	Estimates of mass concentration of BC aerosols (ng/m3)
Air particle analyser 10-stage (QCM) cascade	California Measurements, Inc.	Impactor flow rate	0.24 stand lit/min +/-10%	Size resolved measurements of aerosol mass concentration
		Particle size cut points	> 25,12,6.4,3.2,1.6, 0.80,0.40,0.20,0.10, 0.05 µm	

Impactor				
Dr. Pisharoty sonde	ISRO-SPL, VSSC.	Telemetry range	~ 300 Km	Vertical profiles of pressure, temperature, relative humidity, wind speed, wind direction and altitude
		Telemetry frequency range	403.5 MHz	
Automatic weather station	ACURITE/ Chaney Instruments Co.			Surface pressure, temperature, relative humidity, wind speed, wind direction and rainfall

Observations

Observations were carried out to complete the objectives at the locations presented below.

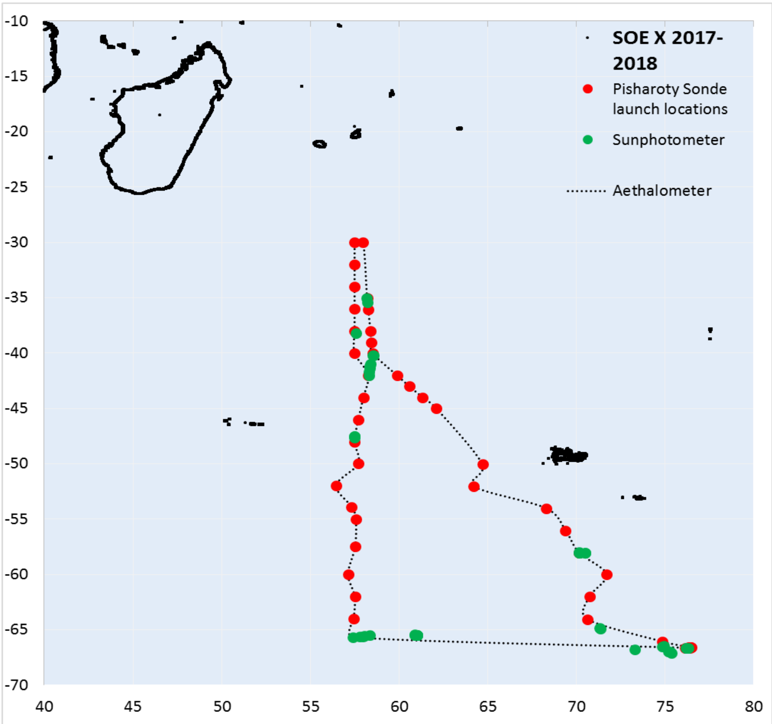

Figure 29. Location of observations carried out during SOE-10 (2017-2018)

Aerosol Optical Depth

A dataset of around 509 data points is obtained from over 48 locations the cruise track as shown below.

Table . 2 Measurement of Aerosol Optical depth measurement

Sr No.	Sunphotometer	
	Latitude	Longitude
1	-35.033	58.183
2	-35.417	58.233
3	-40.167	58.533
4	-40.183	58.55
5	-58	70.133
6	-58.017	70.15
7	-58.017	70.183
8	-58.017	70.5
9	-58.033	70.467
10	-64.817	71.3
11	-64.867	71.367
12	-66.8	73.283
13	-66.483	74.833
14	-66.467	74.917
15	-66.65	76.267
16	-66.617	76.267
17	-66.617	76.283
18	-66.617	76.217
19	-66.617	76.2
20	-66.617	76.183
21	-67.067	75.333
22	-67.033	75.317
23	-66.95	75.25
24	-66.95	75.2
25	-65.5	60.983
26	-65.5	60.967
27	-65.483	61
28	-65.483	61.017
29	-65.467	61.017
30	-65.45	61.017
31	-65.45	60.967
32	-65.45	60.933
33	-65.45	60.9
34	-65.433	60.867
36	-65.55	58.033
37	-65.583	57.967
38	-65.617	57.783
39	-65.667	57.417
40	-47.65	57.483
41	-47.483	57.5
42	-47.5	57.5
43	-42	58.3
44	-41.717	58.3
45	-41.333	58.333
46	-41.167	58.35
47	-40.983	58.383
48	-38.2	57.583

Black Carbon Mass Concentration

The Aethalometer was used to measure the ambient black carbon mass concentration throughout the cruise with a temporal resolution of 5 minutes beginning from Mauritius. The Aethalometer was placed in the Atmospheric lab setup in the ship. The instrument was operated in auto mode with the flow-rate of the aethalometer filtration mechanism maintained at 5 LPM all along the cruise track. The data will be downloaded from the instrument later for error correction, analysis and interpretation.

Aerosol Differential Mass concentration

The aerosol differential mass concentration was measured using Quartz Crystal Microbalance at every 1 degree change in latitude. The data will be downloaded from the instrument later for error correction, analysis and interpretation.

Pisharoty-sonde Ascents

The Pisharoty-sonde balloon operations were carried out at 46 designated stations. The data hence generated will be processed to determine the features of the Marine Atmospheric Boundary Layer (MABL). The data generated will also be processed to determine the features and stability conditions prevailing within MABL at the launch locations. Potential temperature (θ), virtual potential temperature (θ_v), mixing ratio (q), lapse rate, vertical wind shear, vertical air buoyancy, Richardson number (R_i) will be estimated and analysed. The balloon path will also be used to validate the wind trajectories generated by HYSPLIT model to understand the long range transport of aerosols.

Table 3: Locations for .Pisharoty Sonde launches

<table>
<tr><th colspan="4">Balloon launch Locations</th></tr>
<tr><th></th><th>Station name</th><th>LAT</th><th>LONG</th></tr>
<tr><td rowspan="3">PHASE – I</td><td>30S FT</td><td>-30.0</td><td>58.0</td></tr>
<tr><td>35S FT</td><td>-35.0</td><td>58.2</td></tr>
<tr><td>36S FT</td><td>-36.0</td><td>58.3</td></tr>
</table>

	38S FT	-38.0	58.4			
	39S FT	-39.0	58.4			
	40S FT	-40.0	58.5			
	42S FT	-42.0	59.9			
	43S FT	-43.0	60.6	52S RT	-52.0	56.5
	44S FT	-44.0	61.3	50S RT	-50.0	57.7
	45S FT	-45.0	62.1	48S RT	-48.0	57.5
PHASE – II	50S FT	-50.1	64.7	46S RT	-46.0	57.7
	52S FT	-52.0	64.2	44S RT	-44.0	58.0
	54S FT	-54.0	68.3	4S RT	-42.0	58.3
	56S FT	-56.0	69.4	40S RT	-40.0	57.5
	58S FT	-58.0	70.1	38S RT	-38.0	57.5
	60S FT	-60.0	71.7	36S RT	-36.0	57.5
	62S FT	-62.0	70.7	34S RT	-34.0	57.5
	64S FT	-64.0	70.6	32S RT	-32.0	57.5
	66S FT	-66.1	74.8	30S RT	-30.0	57.5
TIME SERIES	TS1 FT	-66.6	76.4			
	TS2 FT	-66.6	76.4			
	TS3 FT	-66.6	76.4			
	TS4 FT	-66.6	76.5			
	TS5 FT	-66.6	76.4			
	TS6 FT	-66.5	76.4			
	TS7 FT	-66.6	76.4			
	TS8 FT	-66.6	76.3			
	TS9 FT	-66.6	76.1			
PHASE – III	64S RT	-64.0	57.5			
	62S RT	-62.0	57.5			
	60S RT	-60.0	57.1			
	57.5S RT	-57.5	57.5			

	55S RT	-55.0	57.6
	54S RT	-53.9	57.3

Auxiliary Data

Additionally, the weather data was generated using the Acurite Weather station to understand the local weather at a time resolution of 1 minute for the entire duration of cruise to understand any local effect on the measurements. For example, the wind direction data will be helpful to eliminate the erroneous data points from the BC mass concentration and the QCM data.

The detailed map indicating the location of each and every successful operation will be complete only after downloading and validating the data from respective

Expected Outcome

The AOD, BC mass concentration, QCM data will be filtered for quality data. The spectral characteristics of the AOD will help in understanding the interaction of incoming solar radiation with the aerosols present in the regions visited as the cruise proceeded. The parameters estimated from the data viz. MABL, Potential temperature (θ), virtual potential temperature (θ_v), mixing ratio (q), lapse rate, vertical wind shear, vertical air buoyancy, Richardson number (Ri) will provide an insight into atmospheric dynamics over the Southern ocean region.The AOD and BC data coupled with the ABL data from the balloons will be processed through SB-DART model in order to understand the actual implications of the aerosol composition that was present during the time of measurement on the climate of the region.

Additional work

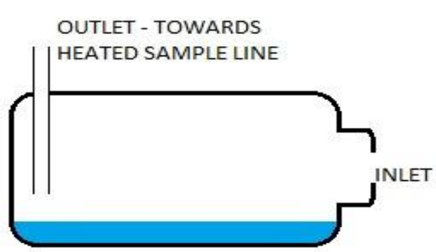

Figure 30. Particle in Liquid Sampler

The aerosol inlet for all the instruments was modified to collect aerosol samples in liquid form. A Nalgene bottle of volume 1 litre was placed horizontal with one end open for free movement of air and the other end was connected to the inlet of the heated sample line.

Since the Aethalometer connected to the heated sample line maintains a continuous flow of 5 LPM, the air in the bottle can be safely assumed to be refreshed at the same rate. 30ml of Milli-Q water was placed in the bottle enabling collection of a part of aerosols suspended in the air stream due to impact deposition. 20ml from the water exposed to the airstream was collected as samples in quadruplets, flash frozen in liquid N_2 and stored in -20^{o}C. Samples were retrieved at designated stations.

Table 4: Locations of aerosol sampling

Sample Name	Sampling Start Location/Time (IST)	Sampling End Location/Time (IST)
A	63^{o}40S; 57^{o}30E / 2030	62^{o}11S; 57^{o}29E / 1000
B	61^{o}57S; 57^{o}23E / 1935	61^{o}32S; 56^{o}59E / 1230
C	59^{o}54S; 57^{o}06E / 1750	57^{o}26S; 57^{o}31E / 0740
D	57^{o}26S; 57^{o}31E / 0750	51^{o}00S; 57^{o}32E / 1550
E	51^{o}00S; 57^{o}32E / 1550	47^{o}30S; 57^{o}29E; 1800
F	47^{o}30S; 57^{o}29E; 1800	39^{o}57S; 57^{o}30E / 1840
G	39^{o}57S; 57^{o}30E / 1840	37^{o}53S; 57^{o}36E 1720
H	37^{o}53S; 57^{o}36E 1720	36^{o}S; 57^{o}30E
I	36^{o}S; 57^{o}30E	34^{o}S; 57^{o}30E
J	34^{o}S; 57^{o}30E	32^{o}S; 57^{o}30E
K	32^{o}S; 57^{o}30E	30^{o}S 57^{o}30E

5.16 Oceanic volatiles and their impact on atmospheric halogens and cloud-forming aerosols in the Southern Ocean

Introduction

Chemistry of the atmospheric marine boundary layer (MBL) over the remote ocean is still poorly understood, especially with regards to the role played by halogens. Halogen compounds have recently been shown to largely control the oxidative capacity of the MBL, accounting for as much as 45% of the ozone destruction (Read et al., 2008; Mahajan et al., 2010). Observations of halogens in the MBL have not been made by any Indian groups to date, and although there has been considerable research on the distribution of ozone around the Indian subcontinent, but observations in the remote Indian Ocean and Southern Ocean are rare (e.g. Lal et al., 1998, 2006; Naja et al., 1999; Saraf et al., 2003; Sahu and Lal, 2006; Sahu et al., 2006).

The role of reactive halogen species (RHS) in atmospheric processes other than ozone destruction has also been studied by international groups. Halogens have been implicated in oxidation of elemental mercury (Hg0) in the polar atmosphere (e.g. Schroeder et al., 1998; Brooks et al., 2006). Their role in H atom abstraction from non-methane hydrocarbons (NMHC) has also been addressed (Saiz- Lopez et al., 2004; von Glasow and Crutzen, 2007). RHS have also been shown to affect the HOx (i.e., [HO2]/[OH]) and NOx ratios (i.e., [NO2]/[NO]) (e.g., Bloss et al., 2005; von Glasow and Crutzen, 2007). Moreover, the involvement of iodine oxides in the formation of ultra-fine aerosol has been investigated by laboratory, field and modelling experiments (e.g. Jimenez et al., 2003; O’Dowd et al., 2004; Saiz-Lopez et al., 2004; Burkholder et al., 2004; Saiz-Lopez et al., 2006; Mahajan et al., 2010; Saunder et al., 2010).

Finally, reaction with halogen compounds has been estimated to be an important, yet largely overlooked, oxidation mechanism for climatically important volatile compounds such as dimethylsulphide (DMS), with model estimates predicting much shorter lifetimes for DMS in presence of bromine compounds, especially in the Southern Ocean (e.g. von Glasow and Crutzen, 2007). This has large implications on the formation of CCN, since oxidation of ocean-leaving biogenic DMS is a major source of sulphuric and methanesulphonic acids susceptible for aerosol nucleation, growth and cloud droplet activation in the clean marine atmosphere (e.g., Charlson et al., 1987; Andreae and Rosenfeld, 2008; Dawson et al., 2012).

Marine microbiota (plankton) produce a great variety of metabolites and waste substances, some of which are volatiles that eventually get into the atmosphere by air-sea exchange processes and act as aersosol and cloud precursors. Evidence so far indicates that plankton influence by these means the optical properties of the atmosphere and consequently the planetary radiative budget (e.g., Lana et al. 2012), but too many unknowns remain for an accurate assessment and modelling of this natural process in both the preindustrial and the Anthropocene Earths. The unknowns on the oceanic side arise from our poor understanding of the ecophysiological mechanisms that make marine microbiota produce volatiles. Gaining knowledge of the underlying biological processes is essential if we are to incorporate climate-biosphere feedbacks in Earth System models.Among the volatiles that generally occur supersaturated in surface waters, and hence undergo a net efflux to the atmosphere (Liss 2007), some of the most important as aerosol and RHS precursors are: -Dimethylsulphide (DMS). Although much progress has been made on the understanding of its production by plankton (Simó, 2001; Stefels et al., 2007) and its global distribution (Lana et al. 2011), the question of which is its main driver, either sunlight or phyplankton taxonomy, is still under debate (Simó & Pedrós 1999; Vallina & Simó 2007). It occurs together with much lower concentrations of its minor relatives COS and CS2.

-Isoprene (2-methyl-1,3-butadiene). It is ubiquitous in the ocean (Broadgate et al. 1997) and has been proposed as a source of marine SOA, as it is over land (Gantt et al. 2009). Phytoplankton isoprene producers just start to be identified (Arnold et al. 2009), and data are too scarce to define its biogeography. Oxidation of isoprene is suggested to give rise to glyoxal, among other products.

-Iodomethanes and bromomethanes. They are produced by macro- and microalgae and (photo)chemical reactions (Carpenter et al. 2012). Together with I2 and sea salt they are a principal source of RHS to the atmosphere, where they participate in ozone loss and act as a source of new nucleated secondary aerosol (O’Dowd et al. 2002). Organic matter, nitrate and marine microbes have been suggested as key regulating factors, but interpretation of the observed oceanic distributions is not straightforward (Butler et al. 2007; Mahajan et al.

2012). A recent global climatology has identified the Indian Ocean as one of the major gaps in the coverage of oceanic halomethane measurements (Ziska et al., 2013).

In the recent past studies have been made to understand the connection between iodine species and the phytoplankton in the ocean. A good correlation between soluble iodine species (SOI) and chlorophyll-a has been reported in the Atlantic (Lai et al, 2011) and the Southern Ocean (Mahajan et al, observations during ISOE-8, 2015 and SOE-9, 2016). Some phytoplankton functional types (PFTs) like prochlorococcus, synechoccocus and diatom were reported to be related to CH_3I concentrations (Lai et al, 2011; Brownell et al., 2010; Hill and Manley, 2009). Diatom species have been observed to be able to release reactive iodine species (e.g. HOI), which has been proposed to participate in SOI production (Hill and Manley, 2009; Baker, 2005). Until now the composition of soluble iodine species in marine aerosols is still unknown and thus specific PFTs have not been identified. The correlation of chlorophyll with iodine species and identification of specific phytoplankton species contributing to the iodine species is not well studied and explored in the Southern Ocean.

Objectives

To complete the Southern Ocean Expedition with multiple objectives that are linked through a multidisciplinary study involving atmospheric and oceanographic observations using state-of-the-art instrumentation.

a) Quantify the impacts of halogens on the chemistry of the open ocean troposphere:
   i. Measure halogens in the atmospheric boundary layer with MAX-DOAS and compare the data with emissions of organohalides to constrain the main source (organic - inorganic) in the marine environment.
   ii. Study the impact of reactive halogen species on the oxidation capacity through interaction with ozone (measured), dimethylsulphide (DMS) (data available from other cruises) and mercury (modelled).
   iii. Study the impact of iodine oxide on particle formation.
   iv. Study the correlation of iodine species with the phytoplankton in the ocean and identify potential phytoplankton functional types (species) influencing the concentrations of soluble or unidentified organic iodine species.

b) Study the distribution of glyoxal in the atmospheric boundary layer and whether the ocean-leaving isoprene flux can explain the atmospheric concentrations.

c) Measure DMS (and probably isoprene) concentrations in continuous in the surface ocean by AP-CIMS, and compare them with mesoscale hydrographic features and their associated patterns of productivity (**The instrument to measure DMS was not available during the SOE-10 and hence observations of DMS were not carried out*)

Materials and Methods

We used state-of-the-art instrumentation in order to achieve the above objectives. Trace gas species were measured in the marine boundary layer along the ships transect. These observations were be made continuously. The instruments are detailed below:

a) Multi Axis Differential Optical Absorption Spectrometer (MAX-DOAS)

This instrument measures the vertical profiles of halogen species (IO, BrO etc.) and oxidized volatile organic compounds in the lower troposphere. The instrument works with scattered sunlight and is placed at an outdoor location with a clear line of sight to the horizon and 1 m of bench space no more than 10 m away from the outdoor unit as per the requirement of the instrument.

b) O_3 monitor - Measures the surface ozone concentrations

Preliminary results:

The data is under process and the results will be reported as soon as possible. The observations made successfully during the SOE-10 are as follows:

Sr. No.	Frequency of Observations	Instruments	Parameters
01	Continuous measurements from Mauritius every 1 min (55 days)	Ozone analyser	Atmospheric ozone concentration
02	Continuous measurements from Mauritius every 10 min (55 days)	Multi-Axis Differential Optical Absorption Spectrometer	Iodine oxide, Bromine Oxide,Nitrogen dioxide, formaldehyde, oxygen dimer etc.

Expected outcome

Some of the specific outcomes expected from the study are detailed below:

1) Quantification of the total impacts of halogens on the chemistry of the marine boundary layer. This is a relatively new field in atmospheric chemistry and our observations will help decide whether the chemistry of halogens is indeed important enough to be included in global chemistry transport models (hence eventually in climate models) for accurate simulation of atmospheric processes.
2) Comparative study of the geographical distributions of atmospheric halogens, other volatile compounds from the Indian Ocean and Southern Ocean. Studies with such a comprehensive spread of measurements of interlinked variables are very scarce. Besides, the Indian Ocean region is poorly studied for most of these compounds, while the Southern Ocean dataset of trace gas species such as halogens and glyoxal are sparse. This study will fill this gap in addition with throwing some light on the processes and environmental conditions linking them through oxidation reactions.
3) Another important outcome is validation of the model predictions for BrO and other trace gases in the Southern Ocean.
4) Quantification of tropospheric ozone concentration and finding its sources. The ozone concentration will help in understanding the presence of aerosols like black carbon.
5) Using the results of the MAX - DOAS we expect to be able to find the cloud index and flag the sky conditions for cloudy or clear sky.
6) Better understating of relationship between the chlorophyll distribution in the ocean and concentrations of iodine species, with respect to other influencing factors like wind speed and wind direction.
7) Identification of phytoplankton species affecting iodine species concentrations.

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5.17 Isotopic characterization of the hydrological cycle over the Southern Ocean

Introduction

Stable isotopes of water act as natural tracers in the water cycle. The usefulness of this natural tracer in understanding the hydrological cycle and atmospheric circulation pattern is well documented. Isotopic ratios in rainwater and water vapor mirror the isotopic composition of moisture source and reflect the fractionation associated with the mechanism of precipitation (Dansgaard, 1964,Rozanski, 1993, Gat, 2005 and Yoshimura, 2015).

In nature there are three stable isotopes of Oxygen (^{16}O, ^{17}O, and ^{18}O) and two stable isotopes of Hydrogen (^{1}H and ^{2}H or D). Out of a nine possible water isotopologues only three are found in measurable concentrations i.e.: H_2O_{16}, H_2O_{18} and HDO. Although normal or light water, which includes only light isotopes (i.e., H_2O_{16}), is much more common, heavy water containing heavy stable isotopes (i.e., H_2O_{18}, H_2O_{17} and HDO) occurs in regular proportions on Earth.

The observed variations of ^{18}O and ^{2}H in the hydrological cycle are relatively small, the heavy isotope content of water samples is usually expressed in delta (δ) values defined as the per mille deviation from the adopted standard representing mean isotopic composition of the global ocean:

Where R_{sample} and $R_{standard}$ are the isotopic ratio ($^{18}O/^{16}O$ or $^{2}H/^{1}H$) in the sample and standard respectively.The internationally accepted standard for measurements of deuterium and oxygen isotopic composition of natural water samples is Vienna Standard Mean Ocean Water(VSMOW) (Coplen et al., 1996). The isotopic ratios $^{2}H/^{1}H$ and $^{18}O/^{16}O$ of VSMOW were found to be equal to:$^{2}H/^{1}H$= (155.95±0.08) $\times 10^{-6}$ (De Wit et al., 1980) and $^{18}O/^{16}O$= (2005.20 ± 0.45) $\times 10^{-6}$ (Baertschi, 1976)

Due to a slight difference in physical and chemical properties of stable water isotopes, they require different latent energy for phase changes. Due to this difference in the properties concentration of water isotopes varies during water phase changes, which is known as fractionation. Water phase changes occur at various spatiotemporal scales in the global hydrological cycle, resulting in relative changes in the spatiotemporal distribution of stable water isotopes. The stability of stable water isotopes and differences in fractionation make them very useful in water transport studies. This isotopic differentiation is commonly described by the fractionation factor α* which is defined as the ratio of the heavy isotope content of the liquid (solid) and of the vapour phase such that $\alpha^*=R_l/R_v>1$. In systems at thermodynamic equilibrium the fractionation factor ae corresponds to the ratio of the saturation vapour pressure of normal water to that of water. The relationships defining the temperature dependence for both isotopes is given by Majoube, 1971 and Horita and Wesolovski, 1994.

Under natural conditions the thermodynamic equilibrium is not always established, for instance during evaporation from an open water surface into an unsaturated atmosphere, with relative humidity, below 100%. In this case, slight differences in the transfer of the light and heavy water molecules through viscous boundary layers at the water-air interface cause additional fractionation. This effective kinetic fractionation was described by Merlivat and Jouzel, 1979.

Past air temperatures can be inferred by either δD or $\delta^{18}O$ in the ice core because the equilibrium fractionation between vapour and condensate is temperature dependent. In addition, the precipitation moisture source information can be derived from the deuterium excess ($d = \delta D - 8\delta^{18}O$) parameter, which mainly reflects the kinetic fractionation process, such as evaporation from the ocean into the atmosphere (Dansgaard, 1964).

Materials and methods

The water vapor was collected cryogenically by placing the condensation trap in a mixture of liquid nitrogen and ethanol. The inlet tubing was placed at a height of 15m above the water surface and covered with a droplet shielding cover to negate the contamination by sea spray or precipitation. The outlet of the glass condensation chamber is connected to a pump. Figure 1 shows the apparatus used for trapping the water vapor. Precipitation was collected using the apparatus shown in Figure 2. The precipitation collector was placed on the topmost deck so that there was no contamination by sea spray. Bucket sampling was done to collect surface water samples. The collected samples will be analyzed for δD, $\delta^{18}O$ using a mass spectrometer MAT253 coupled with a Finnigan GasBenchII. Fig 3 shows the sampling locations.

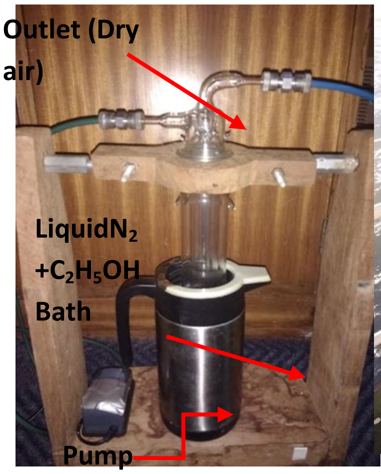

Figure 1. Water vapor trap

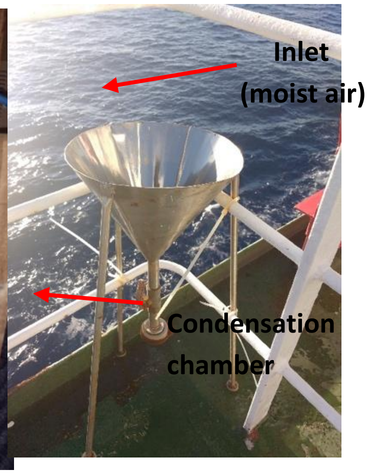

Figure 2. Precipitation collector

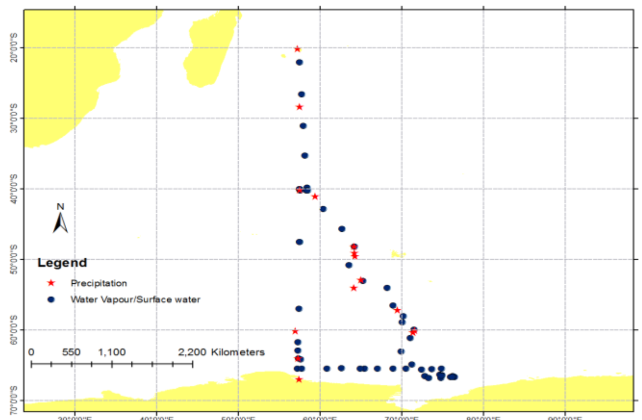

Figure 3 Sampling Locations

Objectives:

In this study, the measurements of δD, $\delta^{18}O$ and deuterium excess in water vapour, precipitation and surface water will be used to:

- Identify the meteorological controls on the variability in water vapour, precipitation and surface water isotopes
- Partitioning of moisture in to locally evaporated and advected sources.
- Isotopic composition of the evaporation flux- investigation of the kinetic fractionation factor in the evaporation model.
- Constrain the GCM's by comparing observed water vapour isotopic composition with the model predicted values.

Table 1. Water Vapour and Surface water sampling Locations

Sample No	**Lat**	**Lon**	**Date**	**Type**	**Parameters**
1	-22	57.5	10/12/2017	Water Vapor/Surface Water	δD, δ18O
2	-26.51	57.79	11/12/2017	"	"
3	-30.99	58	12/12/2017	"	"
4	-35.2	58.2	13/12/2017	"	"
5	-39.75	58.45	14/12/2017	"	"
6	-39.99	57.5	15/12/2017	"	"
7	-40.18	57.56	16/12/2017	"	"
8	-40.18	58.4	17/12/2017	"	"
9	-42.8	60.44	18/12/2017	"	"
10	-45.65	62.7	19/12/2017	"	"
11	-48.14	64.25	20/12/2017	"	"
12	-50.8	63.6	21/12/2017	"	"
13	-53.01	65.3	22/12/2017	"	"
14	-54	68.26	23/12/2017	"	"
15	-56.5	69.01	24/12/2017	"	"
16	-58.02	70.23	25/12/2017	"	"
17	-58.91	70.12	26/12/2017	"	"
18	-59.97	71.58	26/12/2017	"	"
19	-61.15	71.11	26/12/2017	"	"
20	-63.01	70	27/12/2017	"	"
21	-64.85	71.3	28/12/2017	"	"
22	-66.35	74.7	29/12/2017	"	"
23	-65.5	74.91	29/12/2017	"	"
24	-65.53	73.7	30/12/2017	"	"
25	-65.58	72.5	31/12/2017	"	"
26	-66.55	72.9	1/1/2018	"	"
27	-66.81	73.3	1/1/2018	"	"
28	-66.4	74.95	2/1/2018	"	"
29	-66.78	74.85	7/1/2018	"	"
30	-65.5	69.01	9/1/2018	"	"
31	-65.5	67.1	10/1/2018	"	"
32	-65.5	57.25	14/01/2018	"	"
33	-65.5	57.8	15/01/2018	"	"

34	-64	57.4	16/01/2018	"	"
35	-62.9	57.3	17/1/2018	"	"
36	-61.75	57.33	17/1/2018	"	"
37	-64.15	57.66	18/1/2018	"	"
38	-56.99	57.48	21/1/2018	"	"
39	-66.81	73.3	1/1/2018	"	"
40	-66.47	74.9	2/1/2018	"	"
41	-66.65	76.4	3/1/2018	"	"
42	-66.58	76.4	3/1/2018	"	"
43	-66.67	76.49	3/1/2018	"	"
44	-66.54	76.3	4/1/2018	"	"
45	-66.66	76	5/1/2018	"	"
46	-66.67	76.23	6/1/2018	"	"
47	-65.48	70.55	8/1/2018	"	"
48	-65.5	65.5	10/1/2018	"	"
49	-65.5	64.98	11/1/2018	"	"
50	-65.43	62.66	12/1/2018	"	"
51	-65.5	60.9	13/01/2018	"	"
52	-47.51	57.52	25/01/2018	"	"
53	-47.5	57.52	25/01/2018	"	"
54	-40.17	58.4	28/01/2018	"	"
55	-40.18	58.51	28/01/2018	"	"
56	-39.99	57.51	29/01/2018	"	"
57	-39.98	57.5	29/01/2018	"	"

Table 2. Precipitation Sampling Locations

Date	Lat	Lon	Type	Parameters
8/12/2017	-20.09	57.26	Rain	δD, δ18O
12/12/2017	-28.33	57.53	Rain	"
15/12/2017	-40.08	57.5	Rain	"
16/1/2018	-64.01	57.32	Snow	"
16/1/2018	-67.01	57.42	Snow	"
18/12/2017	-41	59.45	Rain	"
19/01/2018	-60.12	57.01	Rain	"
20/12/2017	-48.15	64.19	Rain	"
20/12/2017	-49.05	64.26	Rain	"

21/12/2017	-49.5	64.3	Rain	"
22/12/2017	-52.9	65	Rain	"
23/12/2017	-54	64.19	Snow	"
24/12/2017	-57.19	69.48	Rain	"
26/12/2017	-60.34	71.39	Snow	"
26/12/2017	-60.34	71.39	R+S	"
26/12/2017	-60.08	71.63	Rain	"

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6. 10th Indian Southern Ocean Expedition (SOE-10) Participants

Chief Scientist
Dr. Rajani Mishra, NCAOR

Deputy Chief Scientist
Dr. Anoop Mahajan, IITM

Dr. Sarat Tripathy, NCAOR

Dr. Bhaskar Parli, NCAOR

Dr. Sabu Prabhakaran, NCAOR

Dr. Ravidas Naik, NCAOR

Dr. Amit Sarkar, NCAOR

Dr. Shramik Patil, NCAOR

Mr. Alok Sinha, NCAOR

Mr. Vikash Kumar, NCAOR

Ms. Racheal Chacko, NCAOR

Dr. Venkataramana Vankara, NCAOR

Ms. Nibedita Sahoo, NCAOR

Ms. Pallavi Choudhari, NCAOR

Ms. Anvita Kerkar, NCAOR

Ms. Viola Rodrigues, NCAOR

Ms. Melena Soares, NCAOR

Mr. Riaz Adur, NCAOR

Mr. Bhaskar Kamble, NCAOR

Dr. Hareef Kannemadugu, NRSC

Mr. Rounaq Goenka, NRSC

Mr. Nikhil Baranval, NRSC

Mr. Abhinav Gummalia, NRSC

Dr. Shrivardhan Hulswar, Goa University

Ms. Atiba Shaikh, Goa University

Ms. Neha Shaikh, Goa University

Dr. Abhishek Chauhan, AMITY University

Mr. Laxmikant Bharadwaj Amity University

Mr. Sajikumar Kunjumony K, CMFRI

Mr. Ragesh Namakkal, CMFRI

Mr. Boopathy Palaniswamy, NORINCO

Mr. Michell Manuel, NORINCO

Mr. Shaakir Dar, IISC

Mr. Ankit Swaraj, IISC

Dr. Krushna Vudamala,
IIT Hydrebad

Ms. Stephy Libera, CUSAT

Mr. Venkatesan Selvaraj

Mr. Nivas Niraimathi

Mr. Samuel Varghese

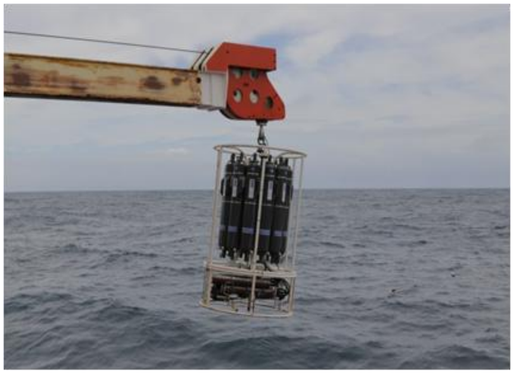
Mr. Udhayakumar Raji

Mr. Rakesh Rao,
Enscitec Production

Dr. Isabella Rosso,
Scripps Institution

Zoelle Hirowitz
Expedition Doctor

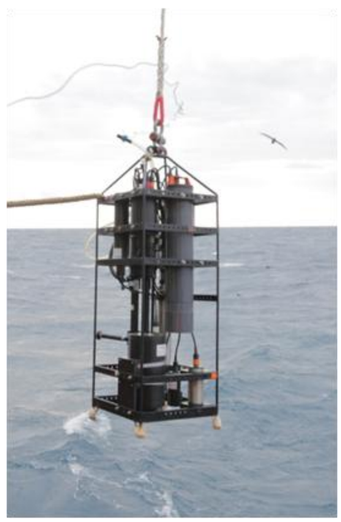
7. Activities of Major Scientific Instruments operated



CTD with Rosette

UCTD operation

LADCP operation

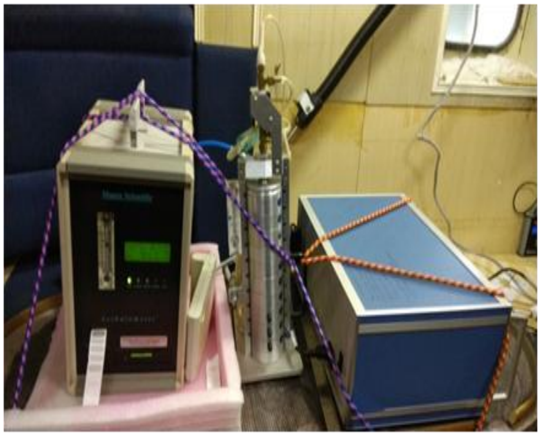


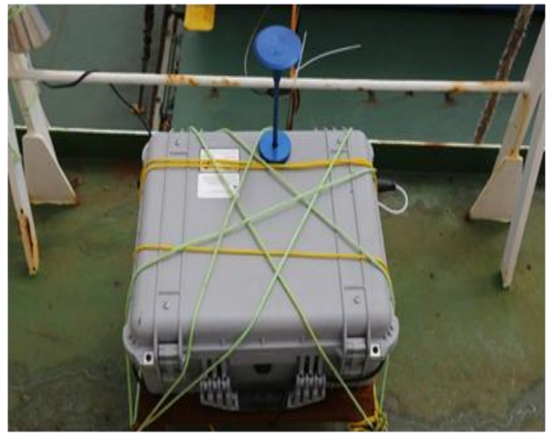
IOP operation

MPN operation

ARGO float deployed

Micro structure profiler operated





Aethalometer and QCM

Particle Size Analyser

UV- Vis Spectrophotometer

MOX-DOAS

Autosal

Sea water filtration Unit

8. Activities (Photographs)

Team all set for Expedition

Christmas celebrations

S.A Agulhus navigation to Ice field

New Year Celebrations

Team Enjoying Snow fall

Republic Day Flag Hoisting Ceremony

Encountering Rough Ocean

Group of Adelie Penguins

A Giant Ice berg

SOCCOM Technical Report Series

http://soccom.princeton.edu

SOCCOM Biogeochemical Profiling Float Deployments from MV S.A. Agulhas ISOE-10

Ship and Expedition ID: MV S.A. Agulhas (NCPOR); ISOE-10

Dates: Dec 9 2017 - Feb 4 2018

Cruise identifier (CCHDO and SOCCOM): 91AA20171209

SOCCOM Cruise Number: YR4-2

Technical Report 2020-8

National Science Foundation Polar Programs PLR-1425989 (Princeton University); NASA NNX14AP49G; U.S. Argo Program (NOAA)

Citation: Talley, L. D., I. Rosso, P. Sabu, N. Anilkumar, R.K. Mishra, K. Johnson, S. Riser, E. Boss, S. Becker, A. Dickson, R. Key, 2020. SOCCOM biogeochemical profiling float deployments from MV S.A. Agulhas ISOE-10 (NCPOR). SOCCOM Tech. Rep. 2020-8. https://soccom.princeton.edu/sites/default/files/imagesfiles/SOCCOM_Yr4-2_91AA20171209_NCPOR.pdf

SOCCOM float deployments from MV SA Agulhas (NCPOR) ISOE-10

Number of SOCCOM floats:	7
Cruise Name or Nickname:	NCPOR
Ship:	MV SA Agulhas (India, NCPOR)
Cruise number:	ISOE-10 (SOE2017-18)
Expocode:	91AA20171209
Chief Scientist or Cruise POC:	CS, Dr. Rajani Kanta Mishra POC, Dr. N. Anilkumar anil@ncpor.res.in POC, Dr. P. Sabu sabu@ncpor.res.in
Departure Port:	Port Louis, Mauritius
Departure Date:	Dec. 9, 2017
Final Port:	Port Louis, Mauritius
Final Date:	Feb. 4, 2018
SOCCOM float responsibility onboard	Dr. Isabella Rosso irosso@ucsd.edu Pre-cruise setup: Greg Brusseau
Link to NCPOR voyage summary	http://www.npdc.ncaor.gov.in/npdc/voyage.action
LInk to NCPOR voyage report	http://www.npdc.ncaor.gov.in/npdc/voyagedatadownload.jsp?filename=reg-00004_Scientific_report_SOE%2010%20%20cruise%20reprt.pdf

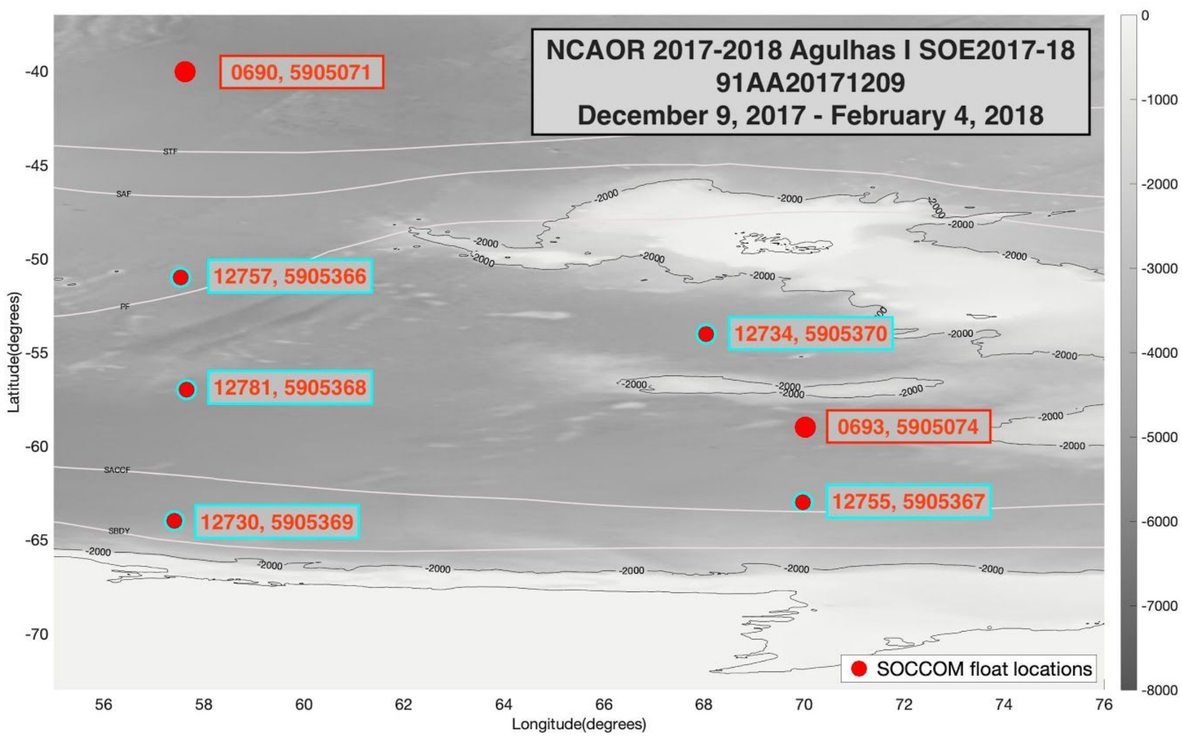


Figure 1. SOCCOM float deployments and CTD stations from MV S.A. Agulhas (Dec 9 2017 - Feb 4 2018). Red with cyan: Apex floats. Red only: Navis floats. Float ID numbers in boxes: (UW ID

2

number WMO ID number). Light curve is the standard Orsi et al. (1995) front (Subtropical) that appears in this latitude range. Other Orsi fronts appear farther south. Other NCPOR CTD station locations are not shown.

Table of Contents:

Table 1: SOCCOM-18 MV S.A. Agulhas (ISOE-10) float deployment details (I. Rosso, SIO)

Description	Nominal location (°S, °E)	Float UW ID	Sensors *	Sta. #	Deploy-ment Date	Deploy-ment Time	Lat.	Lon.	Name (deployer)
1	40°S, 58.5°E	0690	Navis IONFp	1	Dec. 15, 2017	16:39 UTC	40 02.4209S	57 37.2273E	Isa Rosso
		Comments: ***"Sandy" from Long Beach Island Grade School*** Navis better for high resolution to match mooring.//Subsequently: Seabird pH sensor failed at outset on this float.							
2	54°S, 68.0°E	12734	Apex IONFp	3	Dec. 23, 2017	13:19 UTC	54 02.1134 S	68 02.6330 E	Isa Rosso
		Comments: ***"Magma Manker" from Gilroy High School***							
3	58°S, 70°E	0693	Navis IONFp	5	Dec. 26, 2017	02:58 UTC	58 59.7536 S	70 01.5225 E	Isa Rosso
		Comments: ***"Manker Tanker" from Gilroy High School*** Navis better for potential grounding, and high resolution . Another float, another challenge. We first risked to lose the CTD for some loose connections with the winch cable. Then, the winch had some issues (it kind of get stuck if there's a big swell), and we could reach only 1400 m for the cast. There was also some grease on the top part of the float, but thanks to the dream team Susan, Emmanuel and Dana, everything was solved and it turned out it wasn't anything scary after all. I got a full sample collection at this cast, with NCPOR collecting salts and oxygen. I'll soon get the CTD data of the previous and recent casts.//Subsequently: CTD failed on this float after the first profile, during parking phase.							
4	63°S, 70°E	12755	Apex IONFp	6	Dec. 27, 2017	22:27 UTC	63 00.3303 S	69 58.3424 E	Isa Rosso
		Comments: ***"Zazzies, Mac & Cheese" from Seaside Middle School.*** The first icebergs. The ocean is unrealistically flat. Successfully deployed in its box.							
5	64°S, 57.5°E	12730	Apex IONFp	31	Jan. 16, 2018	13:17 UTC	63 59.2186S	57 24.3317E	Isa Rosso

		Comments: ***"FMS Maximum Ride" from Frenship Middle School*** Filtering: super cool plankton, look like super thin hair. One day of snow storm, CTD casts delayed for the bad weather. The tape around the cardboard box containing the float was broken, probably when we moved the float to the storage place. So, Maximum Ride was deployed without the box.							
6	60°S, 57.5°E	12781	Apex IONFp	33	Jan. 21, 2018	18:59 UTC	56 58.83' S	57 39.08' E	Isa Rosso
		Comments: ***''Lil Sinker'' from Frenship High School*** Float endured significant shocks in the ship's hangar during storm, so removed from box, visual inspection, all appeared to be in good shape. First profile looks good.							
7	50°S, 57.5°E	12757	Apex IONFp		Jan. 24, 2018	11:32 UTC	51 00.78 S	57 32.41 E	Isa Rosso
		Comments: ***'Cowboys' from Salinas High School***. Same comment as 12781.							

I = ice enabled
Ice > 1 yr: stay out of ice for first yr
O = oxygen sensor
N = nitrate sensor
F = FLbb
p = pH

A = Apex
CApex = carbon fiber hull Apex
Nav = Navis (Seabird)

Table 2. SOCCOM float sensor information (D. Swift, UW)

```
#~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
IsusInventory.mbari, v1.55 2017/08/17 18:27:25 swift
#~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
For Soccom project:
# WrcId ApfId SbeId  IsusId  OptodeId FlbbId DeploymentOpportunity
#------------------------------------------------------------------------
  7965  12781  9015 769  2676   4411 (MauritiusAgulhas) PtvChk 48"Apf9iSbe41cp
  7973  12757  9024 776  2682   4419 (MauritiusAgulhas) PtvChk 48"Apf9iSbe41cp
  7974  12755  9025 778  2673   4420 (MauritiusAgulhas) PtvChk 48"Apf9iSbe41cp
  7981  12730  9032 796  2717   4427 (MauritiusAgulhas) PtvChk 48"Apf9iSbe41cp
  8054  12734  9287 792  2680   4436 (MauritiusAgulhas) PtvChk 48"Apf9iSbe41cp

#        NpfId SbeId  SunaId  Sbe63Id McomsId      DeploymentOpportunity
#------------------------------------------------------------------------
0690      0690 8486    0820    1363    0137       (MauritiusAgulhas) 66-8607 (2016-2017)
N1Sbe41nSbe63McomsSuna (Ice OK)
0693      0693 8572    0823    1379    0141       (MauritiusAgulhas) 66-8607 (2016-2017)
N1Sbe41nSbe63McomsSuna (Ice OK)
```

Table 3. SOCCOM shipboard measurements August 14, 2020 (L. Talley, SIO)

Measurement	Institution	Contact name & Email	Onboard or ship samples	Data contact	Date Rec'd	Date Archived	Archive location
SOCCOM REQUIRED CALIBRATION OBSERVATIONS							
CTD profile	NCPOR	N. Anilkumar anil@ncpor.res.in	onboard	P. Sabu sabu@ncpor.res.in	Aug 19, 2020 Sabu (final)		(prelim on internal SOCCOM server)
Optical profile	SOCCOM	E. Boss (BB2F #4795) emmanuel.boss@umaine.edu	onboard	P. Sabu sabu@ncpor.res.in	April 30, 2018 Sabu (preliminary)		(prelim on internal SOCCOM server)
Rosette salts	NCPOR	N. Anilkumar anil@ncpor.res.in	onboard P. Sabu, Racheal Chacko	P. Sabu sabu@ncpor.res.in	Aug. 22, 2018 Sabu NCPOR	Nov. 8, 2019	CCHDO http://cchdo.ucsd.edu
Rosette O_2	NCPOR	N. Anilkumar anil@ncpor.res.in	onboard Amit Sarkar	P. Sabu sabu@ncpor.res.in	April 18, 2018 Sabu NCPOR	Nov. 8, 2019	CCHDO http://cchdo.ucsd.edu
Nutrients	SOCCOM SIO	Susan Becker sbecker@ucsd.edu	Frozen, shore-based/ Thawed and run as soon as received	M. Miller mhite@ucsd.edu	Feb. 20, 2018 Melissa Miller SIO	Nov. 8, 2019	CCHDO http://cchdo.ucsd.edu
pH	SOCCOM	Andrew Dickson adickson@ucsd.edu	Shore-based A.Dickson	A. Dickson	May 24, 2018 Andrew Dickson SIO	Nov. 8, 2019	CCHDO http://cchdo.ucsd.edu
Talk	SOCCOM SIO	Andrew Dickson adickson@ucsd.edu	Shore-based A.Dickson	A. Dickson	May 24, 2018 Andrew Dickson SIO	Nov. 8, 2019	CCHDO http://cchdo.ucsd.edu
HPLC	SOCCOM SIO	Susan Becker sbecker@ucsd.edu	Ship to ODF	NASA	April 17, 2018 Crystal Thomas NASA	May 25, 2018	NASA SeaBASS
POC	SOCCOM SIO	Susan Becker sbecker@ucsd.edu	Shore-based UCSB	Feb. 14, 2018 UCSB	March 15, 2018 Georges	May 25, 2018	NASA SeaBASS

					Paradis UCSB		

SOCCOM Shipboard measurements 'metadata' (R. Key, Princeton U.)
The metadata 'readme' is the information that appears in the header of each shipboard measurement data file.
http://soccompu.princeton.edu/DeploymentCruises/Indian/Agulhas_I/2017/91AA20171209/General_Documentation/README.91AA20171209.txt

Table 4. Float and shipboard data servers

Server	url	Purpose
Floatviz (MBARI)	http://www.mbari.org/chemsensor/floatviz.htm	Float profile data including all sensors, quality controlled data
U. Washington Argo float server	http://runt.ocean.washington.edu	U.W. float summaries, diagnostics, engineering data, profiles
U.S. GODAE Argo GDAC	http://www.usgodae.org/argo/argo.html	Real-time and delayed-mode Argo data server (U.S.), high resolution T/S
Coriolis (Ifremer) Argo portal	http://soccom.ucsd.edu/floats/SOCCOM_data_ref.html	Float metadata and graphics
JCOMMOPS Argo data server	http://argo.jcommops.org/ (links to US GODAE for data access)	Real-time and delayed-mode Argo data server (international), high resolution T/S
CCHDO (CLIVAR and Carbon Hydrographic Data Office)	http://cchdo.ucsd.edu/	CTD and discrete rosette sample data (calibration)
NASA Seabass	http://seabass.gsfc.nasa.gov	HPLC and POC discrete samples; bio-optical profiles

Narrative.

The following was principally the official report from SOCCOM included in the overall SOE-10 2017-2018 cruise report. More information is added here.

Introduction

With its unique circulation, where old waters rich in carbon and nutrients are upwelled, and young and dense waters are formed [e.g., Marshall and Speer, 2012; Morrison et al., 2015; Talley 2013], the Southern Ocean represents a key player in the global climate system. Of the total anthropogenic carbon globally absorbed per year, the Southern Ocean contributes half of its uptake [e.g., Takahashi et al., 2012]. However, the uncertainties associated with the carbon system are large [e.g., Mikaloff Fletcher et al., 2006]. The limited number of in-situ measurements and the lack of wintertime and under sea ice observations are one of the biggest gaps for understanding the Southern Ocean's role in the climate and carbon systems. Reducing these uncertainties by increasing the data coverage is, therefore, extremely important. Especially, given the large spatial and temporal variability of dissolved carbon concentration [e.g. Rosso et al., 2017] and air sea CO2 flux [e.g., Takahashi et al., 2009; Resplandy et al., 2014], an observing system able to inform on the carbon parameters at different space and time scales is required.

The Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) is increasing the spatial and temporal coverage of physical and biogeochemical parameters in the Southern Ocean, by deploying a fleet of autonomous profiling floats equipped with temperature, salinity, depth, pH, nitrate, oxygen, fluorescence and backscatter sensors. With a predicted lifetime of 5 to 7 years, the floats are informing about seasonal cycles of biogeochemical parameters, their interannual variability, wintertime and under ice processes, as most of the SOCCOM floats are also enabled to profile under sea ice, store the data and surface to report profiles after ice melts.

SOCCOM is a project supported by the National Science Foundation, under the US NSF award PLR-1425989, and is housed at Princeton University (NJ). It brings together a number of scientists with a physical, biological and chemical oceanographic expertise, from different institutes across the United States. To reach its goal, SOCCOM is building up to 200 floats by 2020, and, at present, it has already 100 floats in its fleet.

A large part of the SOCCOM efforts is also directed toward modeling of biogeochemical cycles, with a focus on model improvement, comparison and better simulation of biogeochemical parameters, using climate models and state estimates [e.g. Verdy and Mazloff, 2017; Rosso et al., 2017]. Together with observational and modeling objectives, a fundamental effort of the SOCCOM project is also invested in outreaching, in order to build a strong line of scientific communication with the general public, and to educate middle and high school students. ``Adopt-a-float'' is one of the programs SOCCOM is promoting, which aims to engage students with scientific research.

An overview of SOCCOM, its new developments, outcomes, data from the profiling floats, and the details about the different working teams associated with the project can be found on the website http://soccom.princeton.edu.

Objectives

In order to increase the spatial and temporal coverage of biogeochemical and physical measurements in the Southern Ocean, it is imperative to understand the gaps in observations, in order to select regions where to deploy the floats. The south Indian Ocean is one of the regions of the Southern Ocean where biogeochemical observations are lacking most. The objective of SOCCOM on the SOE-10 2017-18 expedition was therefore to deploy a series of profiling floats, in order to cover the different regimes in the Indian Ocean: Subtropical, Subantarctic, Polar, and Antarctic frontal zones.

Seven profiling floats were planned to be deployed on the SOE-10 expedition. Nominal float locations (Table 1, second column) were selected prior to the cruise. Analyses of pre-existing Argo floats tracks, hydrography and Lagrangian experiments have been performed prior to the cruise, in order to detect and cover the largest gaps of measurements in the Indian Ocean region covered by the SOE-10 expedition. Model experiments were performed releasing synthetic particles using the particle-tracking model 'Octopus' developed by J. Wang, and horizontal velocities from the Southern Ocean State Estimate of Mazloff et al. (2010).

Materials and Methods

Floats:

Seven biogeochemical profiling floats have been deployed, as part of the SOCCOM project, two of which had been built by Seabird ('Navis floats'), while the remaining by the University of Washington Float Lab, from components purchased from Teledyne/Webb ('Apex floats'). All floats were equipped with a CTD (conductivity-temperature-depth), oxygen, nitrate, pH, optical fluorescence and backscatter sensors, and ice-avoidance software. The floats are programmed to descend and drift at 1000 m for 10 days, then sink to 2000 m after which they resurface profiling through the full 2000 m depth. Data acquisition is made through Iridium Satellite communication and GPS. The list of the SOCCOM floats, with their identification number is provided in Table 5.

Greg Brusseau (UW) tested and prepped the 7 SOCCOM floats in Port Louis before the cruise and loaded them on the ship. All floats tested fine.

The floats were deployed at the conclusion of all the other scientific operations, departing from the station and while the ship was steaming at ~1 knot. The deployment occurred at the ship's aft, using a line strung to the float (or to the cardboard box, if present), with one end of the line tied to a cleat and the other held by the technician. No issues were encountered during their deployment. Each of these floats was self-activating, so no initial operations were required before their deployment to activate them.

Shipboard data

In order to provide quality control and validation for the first depth profile of the floats, a CTD cast down to 2000 m was collected. On the CTD rosette, an additional fluorometer and backscatter sensor (FLBB) was mounted, for this purpose. Furthermore, samples of waters for depths down to 2000 m were required, when possible, for pH, nutrients, POC and HPLC measurements. Winkler oxygen measurements are also an essential part for the quality control and validation process: such measurements were taken by NCPOR personnel. Table 5 shows the number of samples that were collected at the different stations/casts, prior the deployment of each float.

Table 5 Water samples drawn at the floats' deployment location

Nr.	Float No.	St./cast	Parameter	Depths	No. samples
1	Navis 0690	01/01	pH	500 m to 2000 m	5
		01/01	nutrients	500 m to 2000 m	5
		01/04	pH	0 m to 200 m	9 (8 + duplicate)
			nutrients	0 m to 200 m	8
2	Apex 12734	03/01	pH	0 m to 1500 m	5 (4 + duplicate)
		03/01	nutrients	0 m to 1500 m	4
		bucket	nutrients	surface	1
		bucket	HPLC	surface	2
		bucket	POC	surface	2
3	Navis 0693	05/01	pH	0 m to 1400 m	13 (12 + dupl)
		05/01	nutrients	0 m to 1400 m	12
		05/01	HPLC	Surface + DCM	2
		05/01	POC	Surface + DCM	2
4	Apex 12755	06/01	pH	500 m to 2000 m	5 (4 + duplicate)
		06/01	nutrients	500 m to 2000 m	4
		06/04	pH	0 m to 200 m	9
		06/04	nutrients	0 m to 200 m	9
		06/05	HPLC	Surface + DCM	2
		06/05	POC	Surface + DCM	2
5	Apex 12730	31/01	pH	500 m to 2000 m	5 (4 + duplicate)
		31/01	nutrients	500 m to 2000 m	4

		31/04	pH	0 m to 200 m	9
		31/04	nutrients	0 m to 200 m	9
		31/05	HPLC	Surface + DCM	2
		31/05	POC	Surface + DCM	2
6	Apex 12781	33/01	pH	500 m to 2000 m	5 (4 + duplicate)
		33/01	nutrients	500 m to 2000 m	4
		33/04	pH	0 m to 200 m	9
		33/04	nutrients	0 m to 200 m	9
		33/05	HPLC	DCM	1
		33/05	POC	DCM	1
		33/06	HPLC	Surface	1
		33/06	POC	Surface	1
7	Apex 12757	34/01	pH	500 m to 2000 m	5 (4 + duplicate)
		34/01	nutrients	500 m to 2000 m	4
		34/04	pH	0 m to 200 m	9
		34/04	nutrients	0 m to 200 m	9
		34/06	HPLC	Surface + DCM	2
		34/06	POC	Surface + DCM	2

CTD and FLBB: The CTD, winch, and software were operated by P. Sabu, Racheal Chacko and Michell Mathew Manuel.

The Wetlabs FLBB sensor, S/N 4795, was provided by the U. Maine (Emmanuel Boss) through SIO Oceanographic Data Facility (S. Becker). The FLBB was added to the rosette and configured by Michell Mathew Manuel (NORINCO) during the load period. Several tests were performed on the configuration and position of the FLBB after the first station, with direction from Dr. Emmanuel Boss. Dr. Boss noticed that the backscatter was measuring values of 1 order of magnitude larger than expected. The tests included the rotation of the FLBB around its axis, swapping the cables with the NCPOR fluorometer mounted on the rosette and moving the FLBB to a different position on the rosette, parallel to the CTD fish, but facing the opposite direction. No changes were noticed during the tests. Finally, Dr. Boss noticed a mistake in the calculation.

A dark test of the FLBB sensor was performed by covering the light path with a black electrical tape during station #10 (no SOCCOM floats were deployed at this station).

Nutrients (nitrate, nitrite, phosphate, and silicate) samples (30 ml each) were collected during the cruise by Isa Rosso. They were stored at -20°C, and were shipped frozen back to Scripps Institution of Oceanography (SIO), where they were analyzed by the Shipboard Technical Support/ODF lab.

Nutrients were also collected and will be analysed by Dr. Amit Sarkar (NCPOR), using an AA3 instrument. Samples were preserved onboard at -20 C and will be shipped frozen.

Dissolved oxygen was measured using Winkler's method and operated onboard by Dr. Amit Sarkar. Pre-made standards were run at regular intervals throughout the cruise, including right before analysis of samples at all stations. Dissolved oxygens were sampled into 125 ml glass flasks by Dr. Amit Sarkar. As this was the first sample taken from each bottle, leak tests were performed prior to collection of the sample.

Salinity samples were measured using a Guildline Portasal 8400A in the underway lab. 250 ml of water was collected and all samples were run by Dr. P. Sabu, Dr. Racheal Chacko and Stephy Ann Libera. OSIL IAPSO standard seawater batch was used for the standardization of the instrument with each run. Salinities were sampled by Dr. Amit Sarkar.

Optical (HPLC/POC) samples were taken from Niskin bottles at the surface and chlorophyll maximum. For the 2 initial stations, samples were taken only at the surface, using a bucket which was rinsed following the MJ Perry maneuver. For each station, 1-2 L of water were sampled, and filtered immediately or in maximum 4 hours in the semi wet lab by Isa Rosso. In case the filtration occurred hours after the water was sampled, the samples were stored in the fridge. After filtration, filters were stored in the liquid nitrogen dewar and shipped to SIO after the cruise in a liquid-nitrogen charged dry shipper. All HPLC and POC samples were taken by Dr. Isa Rosso.

SOCCOM HPLC samples were processed at NASA GSFC. POC samples were processed at University of California Santa Barbara. Both data sets were archived at NASA SeaBASS. SOCCOM is responsible for the data set.

Samples for HPLC were also collected by Melena Soares and filtered by Ravidas Krishna Naik. Samples were stored at -20 C and will be shipped in liquid nitrogen to India. POC samples were collected and filtered by Melena Soares, using pre-combusted GF/F filters. Filters were stored at -20° C and will be shipped frozen to India.

pH/alkalinity samples were shipped to the US for analysis by Dr. Andrew Dickson's lab at SIO. 500 ml of water was collected, and poisoned with mercuric chloride before being sealed. Drs. Isa Rosso and Amit Sarkar took all pH/alkalinity samples.

pH/alkalinity samples were also collected and analysed by Dr. Amit Sarkar and Melena Soares.

Underway thermosalinograph. 51 XCTD measurements (conductivity, temperature and depth surface to 1100 m profiles) every 30 mi between 65° S and 40° S, and 117 UCTD along the ship track (every 30 mi) were operated by the team of Dr. Sabu Prabhakaran. Additionally, sea surface temperature and samples for salinity measurements were taken every 6 hours. No additional underway instruments were mounted on the ship.

Underway pCO_2 No measurements of pCO_2 were taken underway.

Preliminary results

The location and time of deployment for the seven floats are listed in Table 2. All the floats have provided the first test profile after 1 day of cycle, which showed good performance of each sensor (figures in the ''SOCCOM first profiles'' below show property/depth profiles for each deployed float). Initial profiles are quality controlled using data from the CTD casts, both from the sensors mounted on the rosette (CTD and FLBB), and from water samples (oxygen and salinity from NCPOR; pH, nitrate and HPLC/POC from SIO).

All the floats have been performing well in their following 10-day cycles, except for the two Navis floats and the last float deployed, the Apex #12757. Navis float #0690, in fact, showed a malfunction in the pH sensor almost immediately after the first test cycle. Furthermore, the CTD on Navis float #0693 stopped working after two cycles. Prior to the deployment of this last one, some grease was noticed at the base of the bolts on the top of the float. Immediate discussion was carried on with lead float engineer Dana Swift at UW, part of the SOCCOM project. After careful visual analysis, it was decided that the grease was not a sign of a malfunction, but it was due rather to overuse of silicone to seal the float. However, following the failure of the CTD on this float, after only a few days in the water, more investigation will be carried on, together with Seabird Navis.

On January 18th, the ship was hit by a strong storm, with constant winds at ~40 kn and an initial wind gust of 97 kn (this large value was reported by the Captain and Chief Mate, but not recorded in the atmospheric instruments used by the Indian scientific party). Two remaining floats, which were kept inside their cardboard boxes (Apex #12781 and #12757), were secured in the helicopter hangar, together with the majority of other scientific gear (wooden crates, samples, totes). All the items got loose, and went crashing against each other. The situation got worse when the 2 engines of the vessel suddenly stopped working, which took many hours for the engineers to get the engines back and the ship under control again. The day after it was possible to clean and secure the items in the hangar once again, and to inspect the 2 floats that were caught in the crash. From a visual inspection, performed by Isa Rosso and the co-chief scientist Anoop Mahajan, the floats looked intact: neither sensors nor antenna were bent, and after discussion with Dana Swift, it was decided to proceed with their deployment. Unfortunately, the pH sensor of the float Apex #12757 failed. This is probably due to a damage to the relay in the sensor, consequently to the repeated impacts absorbed by the float during the storm. Dana Swift has programmed the float to profile more frequently, in order to try to get the relay free.

Expected outcome

Data visualization is available at http://soccom.princeton.edu/soccomviz.php using the SOCCOMViz platform. Also, data (both QC and noQC) are publicly accessible and usable for any scientific study from the first acquired profile, using a FTP platform through the website http://soccom.princeton.edu/content/float-data-ftp-access.

As part of the ``Adopt-a-Float'' program, students from 5 different schools in the US (Table 7) have followed the journey of the expedition through the blog that Isa Rosso has updated during the cruise (http://soccomatsea.blogspot.com), and have been learning about the Southern Ocean waters, by discussing with their school teacher, and plotting data using the graphical SOCCOMViz platform. It is a success to see many young students excited about science, engaged with research and passionate about understanding our oceans.

Data that the floats will be collecting for the next 5 to 7 years will provide a source to study seasonal cycles of biogeochemical parameters in an area that has been historically poorly sampled, and help to understand the variability of carbon fluxes and cycle. From the trajectories of the floats, much can be learned about pathways of waters at 1000 m in this area. Data will also be used to inform state estimate models, such as the Biogeochemical Southern Ocean State Estimate (BSOSE; Verdy and Mazloff, 2017), which by acquiring every available observation and by reducing the misfit between model solution and observations, it aims to provide a more realistic simulation of the biogeochemical and physical properties of the Southern Ocean.

Table 6: Name of floats from the ''Adopt-a-float'' program. Listed are also the schools which participated in the outreach program.

Float #	*Float Name*	School
1	*Sandy*	Long Beach Island Grade School
2	*Magma Manker*	Gilroy High School

3	*Manker Tanker*	Gilroy High School
4	*Zazzies, Mac&Cheese*	Seaside Middle School
5	*FMS Maximum Ride*	Frenship Middle School
6	*Lil Sinker*	Frenship High School
7	*Cowboys*	Salinas High School

Brief discussion and conclusion

Dr. Sabu Prabhakaran provided unprocessed data from the CTD and other sensors mounted to the rosette. This will be further disseminated by the SOCCOM team, and combined with the various analyses taken from bottle samples. This will then be used to validate the calibration of the sensors on the floats during their initial cast. Comparison of common measurements taken and analyzed by the SOCCOM team and by NCPOR will be beneficial for both groups.

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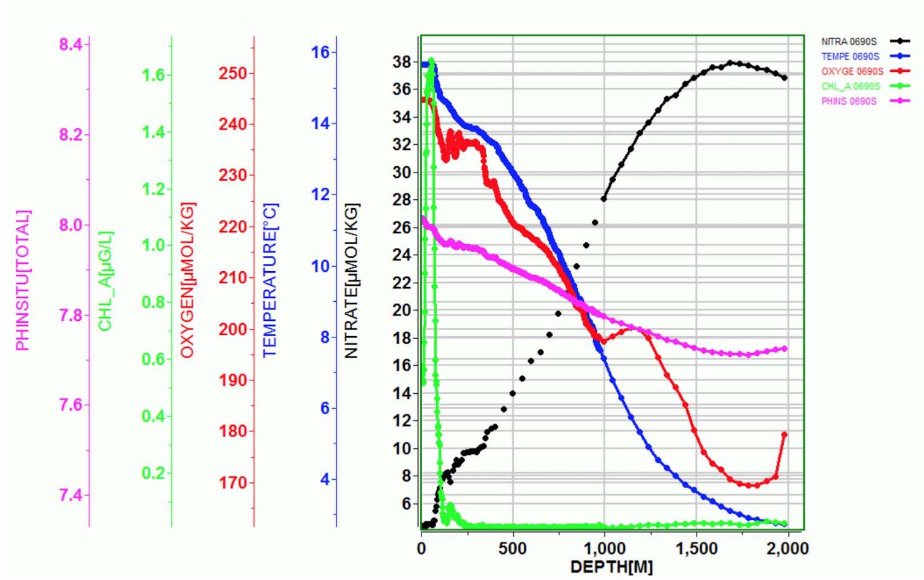
SOCCOM Float First Profiles

0690 NCAOR Agulhas I 12/15/17

40 02.4209S   57 37.2273E

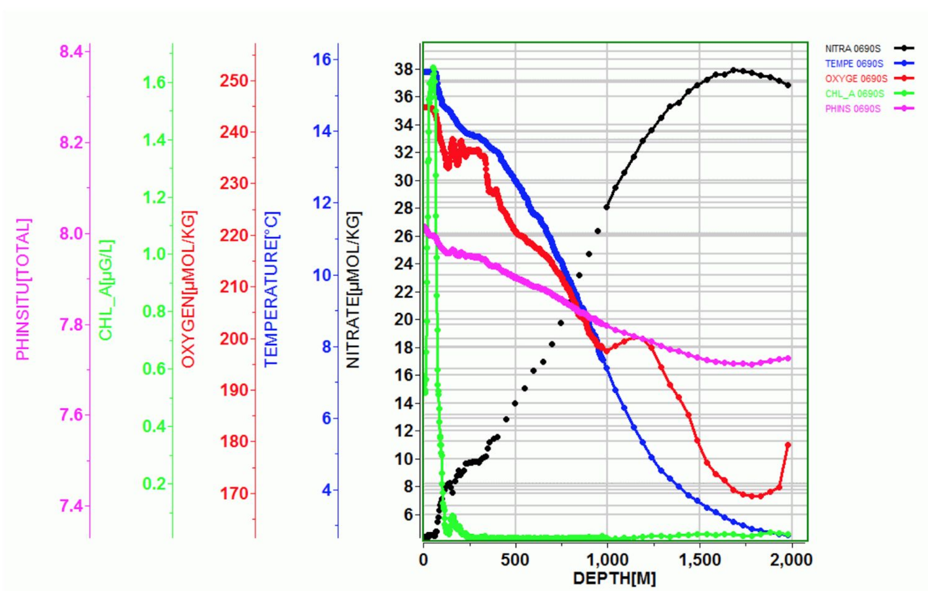
'Sandy'



12734 NCAOR Agulhas I 12/23/17

54 02.1134 S   68 02.6330 E

'Magma Manker '

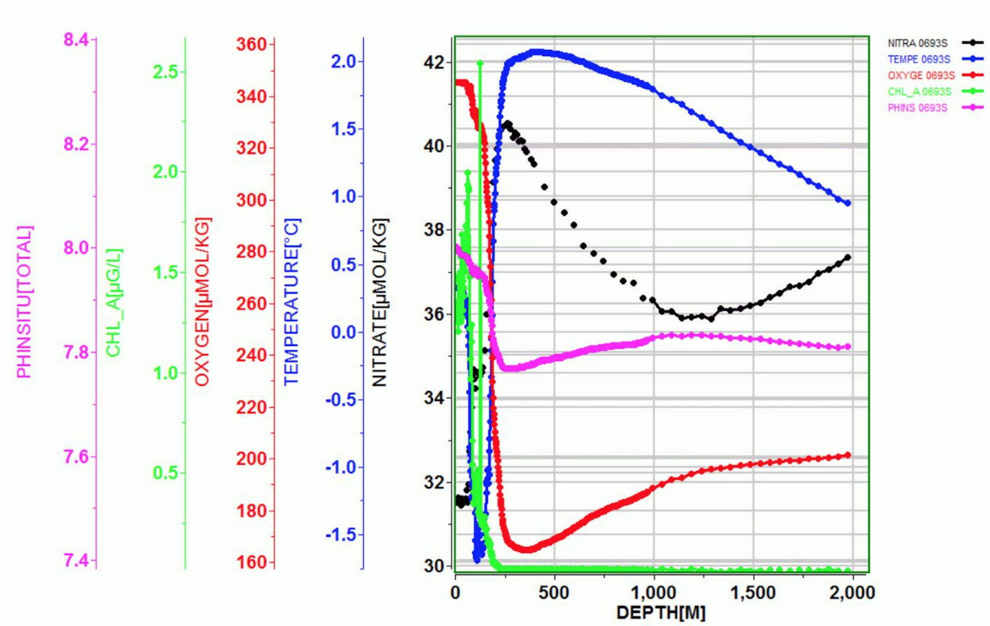


0693 NCAOR Agulhas I 12/26/17

CTD failed on profile 2

58 59.7536 S   70 01.5225 E

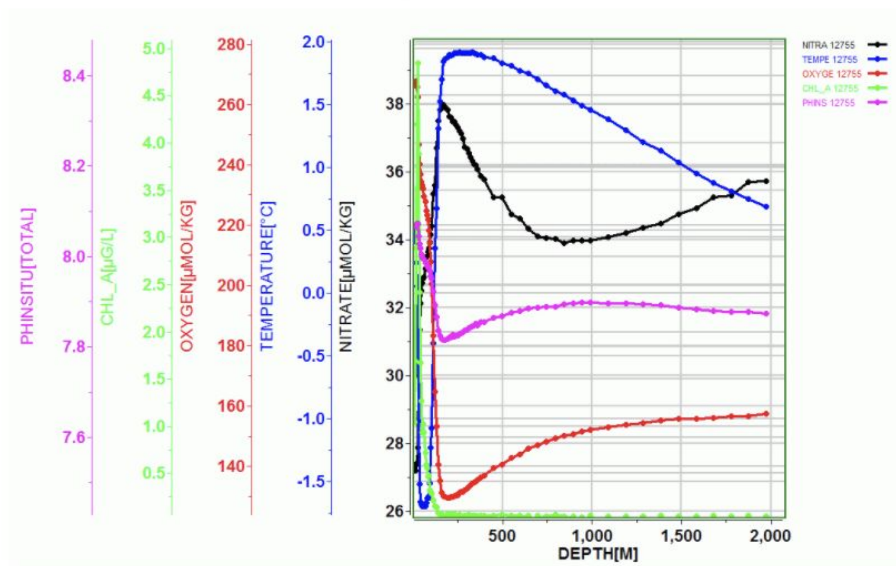
'Manker Tanker '



12755 NCAOR Agulhas I 12/28/17

63 00.3303 S   69 58.3424 E

'Zazzies, Mac & Cheese '

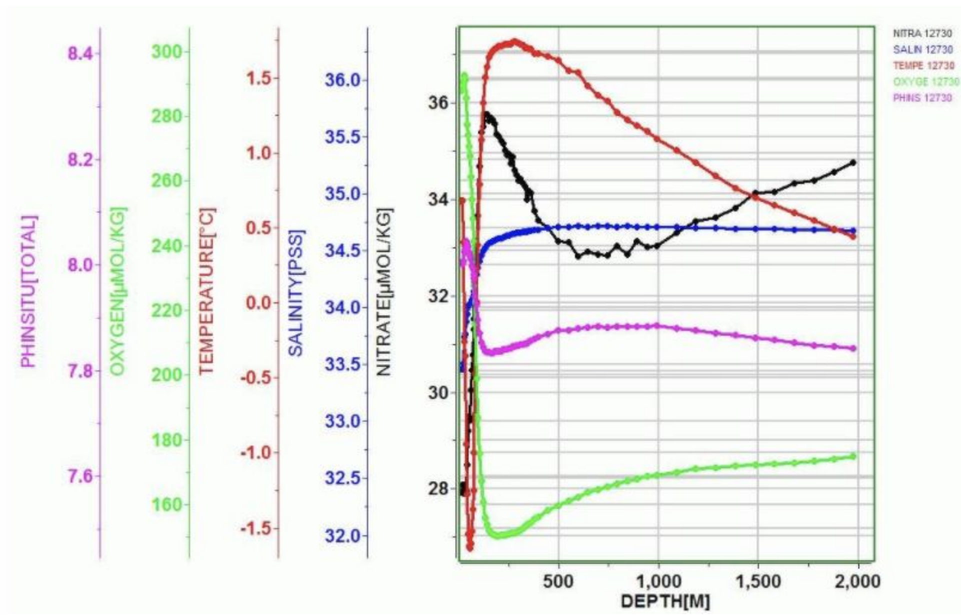


16

12730 NCAOR Agulhas I 01/17/18

63 59.2186 S 57 24.3317 E

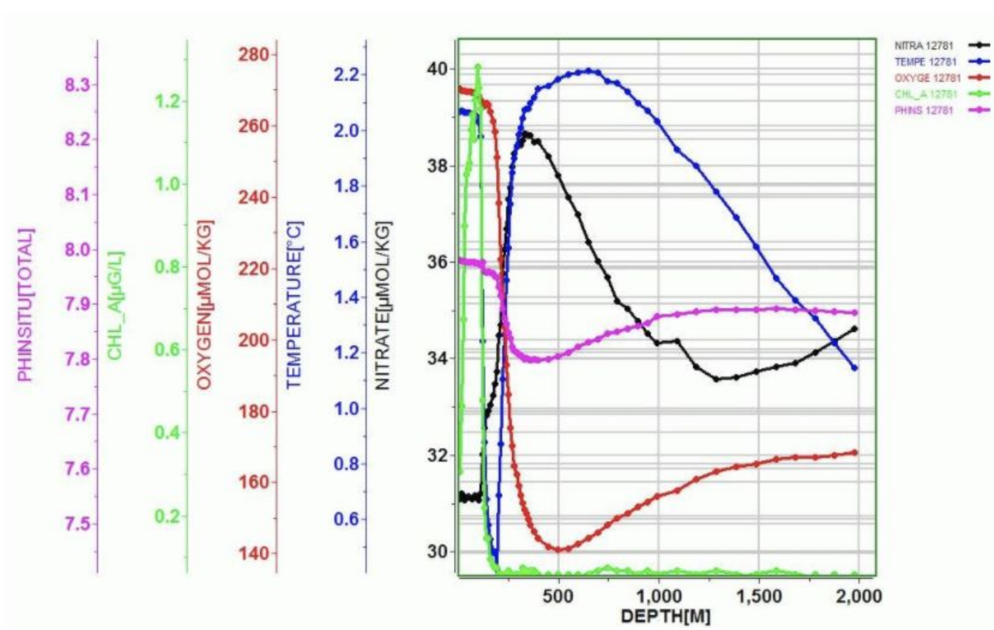
'FMS Maximum Ride '



12781 NCAOR Agulhas I 01/22/18

56 58.83' S, 57 39.08' E

'Lil Sinker'



17